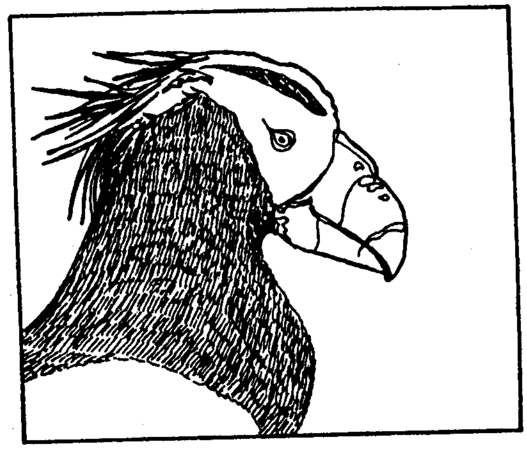
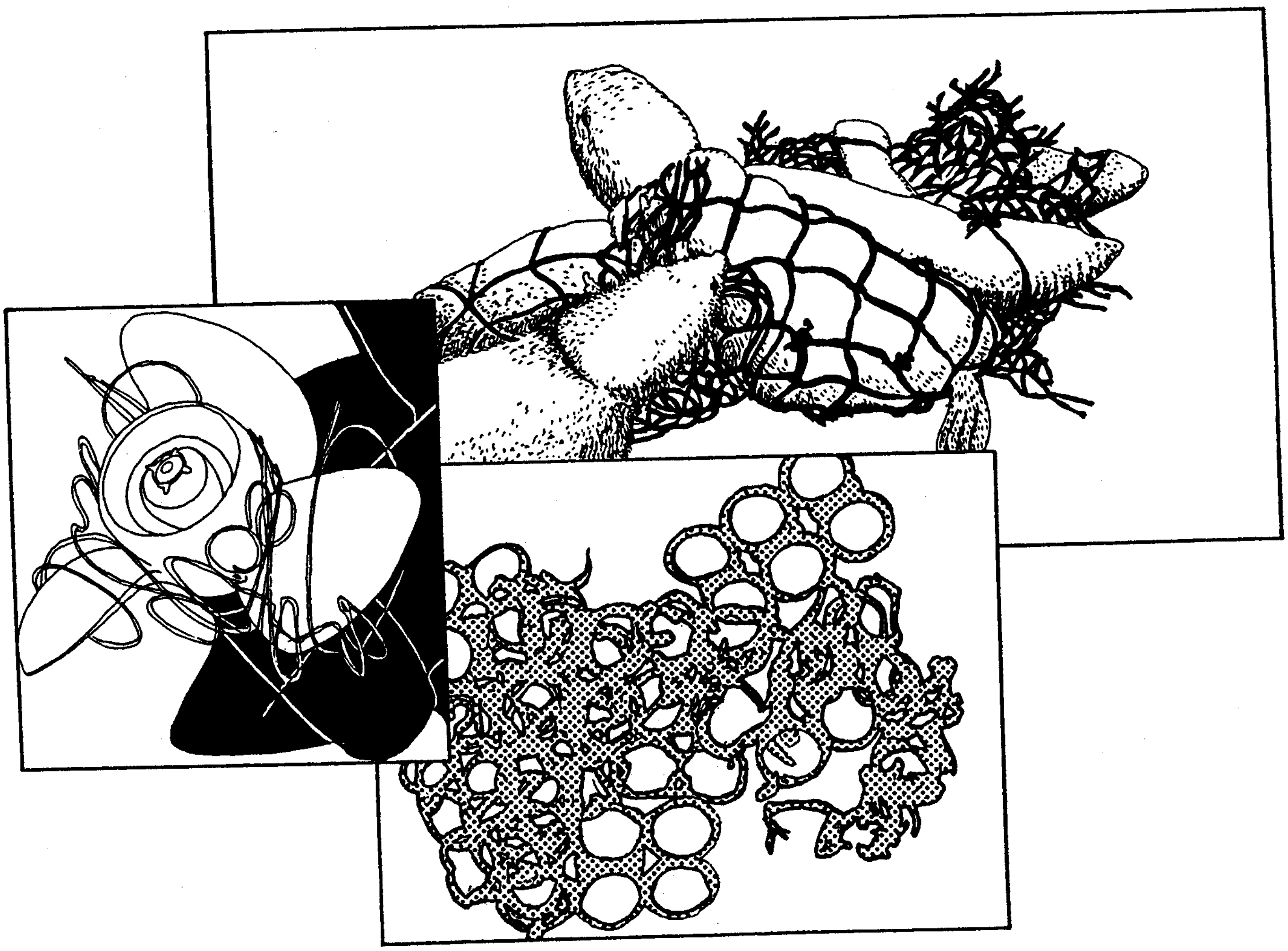
SESSION I



AMOUNTS, TYPES, DISTRIBUTION, AND SOURCES OF MARINE DEBRIS



QUANTITATIVE ESTIMATES OF GARBAGE GENERATION AND DISPOSAL IN THE U.S. MARITIME SECTORS BEFORE AND AFTER MARPOL ANNEX V

J. Cantin, J. Eyraud, and C. Fenton
Eastern Research Group, Inc.
Arlington, Massachusetts 02174, U.S.A.

ABSTRACT

Annex V of MARPOL 73/78 is regarded as an important instrument for reducing the amounts of plastics and other debris discarded into the ocean. Estimates of the aggregate quantities of garbage discarded are outdated, however, and represent only order of magnitude efforts. In this paper, the authors present updated estimates of the amounts of plastics and other debris generated in the U.S. maritime sectors.

The analysis covers both public and private sectors, including merchant marine vessels active in U.S. trade; commercial fishing vessels; recreational boats; research and industrial vessels; U.S. Navy, Coast Guard, and Army ships; and vessels and structures associated with offshore oil and gas operations. Current disposal practices as well as disposal practices under Annex V are analyzed and used to develop estimates of how the disposition of garbage generated at sea, i.e., the amounts dumped overboard, brought back to shore for disposal, and incinerated, will change under the new regulations.

INTRODUCTION

Two questions which underlie the debate over the U.S. ratification of MARPOL Annex V are: (1) How much garbage is being dumped overboard from vessels? and (2) What effect would the specific restrictions contained in Annex V have on the overall marine debris problem? Throughout the numerous congressional hearings which led up to U.S. ratification, only one source of aggregate data, a 1975 study by the National Academy of Sciences (NAS), was identified which addressed these questions. That study, however, examined the entire world fleet and included sources of debris which will not be regulated by Annex V (Table 1). It also made no attempt to account for actual disposal practices, reporting instead on the quantities of garbage "potentially" dumped (NAS 1975).

The present study utilizes current information for the U.S. maritime sectors to develop current and more comprehensive estimates of garbage

In R. S. Shomura and M. L. Godfrey (editors), Proceedings of the Second International Conference on Marine Debris, 2-7 April 1989, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-154. 1990.

Table 1.--Global marine litter estimates (National Academy of Science 1975).

Garbage types and sources	Ton/year	Percent
Sources regulated under MARPOL Annex V		
Crew-related wastes		
Merchant marine	11,000	1.8
Passenger vessels	2,800	0.4
Commercial fishing	34,000	5.4
Recreational boats	10,300	1.6
Military	7,400	1.2
Oil drilling and platforms	400	0.1
Commercial wastes		
Merchant cargo wastes or dunnage	560,000	89.5
Annex V subtotal	625,900	100.0
Sources not regulated under MARPOL Annex V		
Fishing gear loss	100	1.0
Loss due to catastrophe[a]	10,000	99.0
Non-Annex V subtotal	10,000	1000.0
Total	636,000	100.0

[a]Includes debris from shipwrecks or marine storms.

quantities. The main components of the model are: vessel populations, entrances to U.S. ports, crew sizes, garbage generation factors, and plastics as a percent of total garbage. It also fills a gap left in previous studies by addressing historical shipboard disposal practices and changes in practice expected to result from implementation of Annex V. It must be noted, however, that few direct measurements of garbage generation and disposal practices exist. The methodological improvements offered in this study are based on updated data where they exist, and on substantial anecdotal information collected throughout the course of broader regulatory studies of MARPOL Annex V (Eastern Research Group (ERG) 1988a, 1988b).

The study first reviews information related to the sources, types, and quantities of garbage generated in the various maritime sectors. Data on per capita garbage generation, crew size, voyage length, and annual ship utilization factors are used to derive estimates of per voyage, per vessel, and annual aggregate garbage quantities generated. Estimates are made for the following sectors:

- Merchant shipping.

- Commercial fishing.

- Commercial passenger vessels.
- Recreational boating.
- Offshore oil and gas operations.
- Research and other miscellaneous vessels.
- U.S. Navy, Coast Guard, Army, and other government vessels.

An analysis of historical garbage disposal practices in these sectors is used to estimate the pre-Annex V garbage quantities dumped overboard, brought back to shore for disposal, or burned in marine incinerators. Under MARPOL Annex V, ships may be forced to alter their current disposal practices. An analysis of options available for compliance with Annex V is used to derive the post-Annex V disposition of vessel garbage.

GARBAGE ESTIMATION PARAMETERS

This section reviews the types and quantities of garbage generated in the maritime sectors. This information is combined with data on vessel populations, crew sizes, and voyage lengths from the supporting statistical section to produce estimates of the per voyage, per vessel, and aggregate annual garbage quantities generated.

Types of Garbage Generated

Several types of garbage are generated by vessels operating at sea. In this study, "domestic" garbage refers to general garbage such as galley refuse (food wastes, food packaging materials) and garbage from the hotel areas of the vessel (discarded items such as smoking materials and packaging, shampoo bottles, and razors). Wastes associated with normal ship operations, such as rags and containers, are also included. Some vessels generate an additional amount of "commercial" waste. Examples include cargo dunnage, spent fishing gear, and disposable or single-use oceanographic research instruments. These are discussed separately.

Domestic Wastes

Several sources of information on the quantities of garbage generated by ships are available. A series of studies done for the Intergovernmental Maritime Consultative Organization, the predecessor to the International Maritime Organization (IMO), are judged to represent the best available estimates (IMO 1987). These rates, representing per capita daily quantities, were reported as follows:

- Harbor vessels--1.0 kg (2.2 lb).
- Inland and coastal vessels--1.5 kg (3.3 lb).
- Oceangoing cargo vessels--2.0 kg (4.4 lb).
- Oceangoing cruise vessels--2.4 kg (5.3 lb).

As shown, the rates vary depending upon the type of vessel and where the vessel operates.

These rates appear consistent with those obtained elsewhere. The U.S. Navy, for example, examined garbage generation aboard naval ships in 1971 (Naval Ship Engineering Center 1971) and again in 1988 (L. Koss and Lt. Mullenhard, U.S. Navy, pers. commun. 1988), and reported estimates of 1.39 and 1.43 kg/person/day (3.05 and 3.15 lb), respectively. On land, the U.S. Environmental Protection Agency (EPA) estimates that each person generates an average of 1.82 kg (4.0 lb) of garbage per day (National Solid Waste Management Association (NSWMA) n.d.). Thus, the rates from the IMO studies appear consistent with those obtained elsewhere.

In this study, the IMO rates for oceangoing cargo and cruise vessels are applied respectively to cargo and passenger vessels which operate over the open ocean. The IMO rate for inland and coastal vessels is applied to crafts which travel inland or along the coastline.

Commercial Wastes

Several classes of vessels generate wastes associated with their commercial activities. These wastes are distinct from any operational wastes generated through normal vessel repair and maintenance activities, which are included under the category of domestic wastes.

Commercial cargo wastes or dunnage.--The term "dunnage" covers materials such as timber, plywood, pallets, rope, and plastic sheeting used to protect, separate, and secure cargo carried in break-bulk form. In the study (NAS 1975), these types of cargo wastes dominated the aggregate waste quantity estimates (Table 1). Since the mid-1970's, however, the trend towards containerization, and changes in cargo handling methods, are believed to have greatly reduced the amount of dunnage used. Cargo carried by containerships or other types of intermodal ships (barge carriers, roll-on/roll-off) is generally unloaded for transshipment in port without being disturbed. According to officials of the American Institute of Merchant Shipping, therefore, the "vast majority" of cargo ships now produce no dunnage waste (J. Cox, American Institute of Merchant Shipping, pers. commun. 1988).

The quantities and types of dunnage still used in general cargo trade vary, and depend upon the type of cargo being carried. Break-bulk shipments of food products, for example, use mainly cardboard for separation and protection of the cargo. For a highly explosive shipment of ammunition, however, extensive wooden encasements are constructed to protect against movement of the cargo. In such cases, tens of thousands of board feet of lumber may be used. Palletized cargoes may be shrink-wrapped and secured with steel or plastic strapping, but these are not normally removed prior to final delivery at the customer's facilities. Lumber and plywood are the most common materials used.

Marine terminal operators familiar with the loading and unloading of break-bulk ships indicate that very little plastic waste is generated. One reported use for plastic is to capture leaks of moisture or hydraulic fluids in the vessel's cargo hatches. This plastic would likely be removed when the vessel is being unloaded. As indicated, plastic shrink-wrap is used with palletized cargo, but this is generally not removed either on board the ship or in port.

Estimates of per-vessel and aggregate dunnage quantities are difficult to make based upon the limited data. The study (NAS 1975) estimated that general cargo ships generate up to 285 tons of dunnage per year. This estimate contrasts significantly with information provided by marine terminal operators and shipping interests. Due largely to the trend towards containerization of cargo, there appears to be much less dunnage used today. Relying on current reports, this study assumes that two-thirds of the general cargo vessels entering U.S. ports generate dunnage in the form of lumber, one third generate only cardboard, and that 10% generate plastic waste. The quantities used are estimated as follows:

- Lumber--48.6 m^3 (approximately 20,000 board ft) per vessel entrance.
- Cardboard--23.6 m^3 (30 yd^3) per vessel entrance.
- Plastic--assumed to be generated by only 1 of every 10 break-bulk ships entering U.S. ports, in minimal quantities of 0.12 m^3 (4.0 ft^3) per entrance.

As the estimates presented later will show, under these assumptions the amount of waste generated by general cargo ships represents only a small proportion of the total garbage volume regulated by Annex V. Furthermore, overall estimates of plastics are not particularly sensitive to assumptions regarding dunnage volumes.

Fishing gear wastes.--Commercial fishing activity also contributes to the problem of marine debris, and to plastics in particular. Whether trawl gear, set nets, or lines are being used, occasional fouling of equipment, such as the tearing or twisting of nets and lines, will occur. During repair, portions of nets, excess line, floats, and other gear wastes may be generated. All such materials are nowadays made of synthetics, and are prohibited from disposal under Annex V. In addition to these items, substantial quantities of fishing gear are also lost accidentally. Annex V, however, does not cover this category of debris, hence no estimates are made here.

Limited information is available on the amounts of gear waste generated. The Foreign Fisheries Observer Program, National Marine Fisheries Service (NMFS) has monitored fishing gear repair operations on board foreign vessels active in Alaskan waters. Berger and Armistead (1987) analyzed data from this program and found that fishing gear repair operations took place about once every 4.9 days. The U.S. vessels active in the same fisheries report a similar incidence of gear repair (J. Gnagey, Alaska Trawl Fisheries, pers. commun. 1988; Z. Grader, Pacific Coast Federation of Fishermen's Associations, pers. commun. 1988). Discarded webbing was found to be typically small, with only 21.2% of pieces deemed to be "of a mesh size or area thought most likely to entangle marine mammals" (Berger and Armistead 1987). Some 57.9% of discarded pieces consisted of "primarily loose strands of twine or pieces with a mesh size of less than 100 mm."

Working with these data, the amount of gear waste generated over a typical cruise is estimated to be relatively small. Assuming that (1) the average piece of webbing produced during net repair is 1 m^2, (2) webbing is composed of 15 mm diameter twine (Uchida 1985), and (3) the incidence of net repair and discard is twice per week, than the volume of waste generated over even a 30-day fishing expedition would amount to just over 0.12 m^3 (4 ft^3) of net material (ERG estimates).

Evidence suggests that these estimates from the Alaskan fisheries may represent an upper bound on the frequency and amount of fishing gear waste discarded. Beach surveys have found the concentration of fishing gear waste off the Alaskan islands to be among the highest noted anywhere (e.g., Merrell 1985). Discussions with fishery representatives elsewhere in the United States have indicated that net repair operations while at sea are relatively less common. Moreover, net fragments and floats in other fisheries are reported to be retained on board for use in repair operations, rather than discarded. Spare nets may also be carried in order to avoid at-sea repairs completely (ERG 1988a, 1988b). In this study, it is assumed that the average volume of fishing gear waste generated in all U.S. fisheries is half of that calculated for Alaska. An estimate of 0.03 m^3 (1 ft^3) of gear waste per week at sea is assumed.

Nongear fishing wastes.--Certain fisheries produce additional quantities of wastes due to their use of specialized fishing techniques. These include longline fishing, which uses packaged bait (B. Alverson, Longliner Vessel Owners Association, pers. commun. 1988), and the herring fishery, which utilizes quantities of packaged salt (J. Kaelin, Associated Fisheries of Maine, pers. commun. 1988). Longline bait is sold frozen, with packages wrapped in plastic, packed in cardboard boxes, and secured with plastic strapping. Chemical light or Cyalume sticks are also used to attract fish. These sticks, about the size of a pencil, are themselves made of plastic. Salt used in the herring fishery comes in large plastic bags.

Available estimates of marine waste disposal do not address this source of waste. The Center for Environmental Education (CEE) reports that longline gear is used in at least five different fisheries (CEE 1986), and that longline vessels can bait up to 5,000 hooks per day. In order to capture the additional wastes produced by vessels in these fisheries, it is assumed in this study that they generate twice the normal volume of fishing gear waste.

Research vessel wastes.--Research vessels may generate additional plastic wastes in the form of packing materials from research instruments brought on board, and from disposable measuring instruments used in monitoring oceanic experiments. Based on discussions with representatives at various research institutions, an additional 0.12 m^3 (4 ft^3) of plastic waste per voyage is assumed.

Dry Versus Wet Garbage

The nature of the MARPOL Annex V regulations makes it necessary to estimate separately the amounts of "wet" garbage (food waste) and "dry" garbage generated. Many vessels are expected to separate plastics from their dry garbage and then dispose of the remainder while in areas where no Annex V restrictions apply. Some, however, may have to retain all dry garbage for onshore disposal (and even wet garbage, in some cases) depending on whether they operate in Annex V "special areas" or in coastal waters. (Special areas currently include the Mediterranean Sea, Baltic Sea, Red Sea, Black Sea, and Persian Gulf Areas; Table 2.)

The dry garbage component of the overall solid waste stream is estimated based on the recent U.S. Navy study (Koss and Mullenhard, pers. commun. 1988). In this study, dry garbage accounted for 59.4% of domestic waste by weight, while wet garbage accounted for 40.6%. These percentages are similar to those found in the earlier, more extensive Navy studies, where the dry garbage component was estimated at 43.6%.

Plastics as a Percentage of Total Wastes

Annex V places a complete prohibition on the overboard disposal of plastics. Estimates of the percentage of the overall vessel waste stream accounted for by plastics are needed in order to develop projections of the quantity of garbage that may be brought back to shore for disposal.

The EPA estimates that plastics represent 6.5% (by weight) of all household and commercial solid waste on land (NSWMA n.d.). The relevance of this estimate to vessel operations is uncertain, however, because of likely differences in the types of waste generated at sea. In the national EPA estimate, paper and paperboard waste makes up 42% of the total, and yard waste accounts for another 16%. Garbage generated at sea is likely to contain much less paper waste and no yard waste. Under these assumptions, plastics would represent a larger share of the waste stream at sea than it would on land. At the same time, though, national estimates would include discards of durable plastic objects and industrial plastic waste, very little of which is generated at sea.

Studies done by the U.S. Navy in 1971 (Naval Ship Engineering Center 1971) and 1988 (Koss and Mullenhard, pers. commun. 1988) represent the only direct estimates of plastic wastes based on actual operating experience. In 1971, plastics were found to account for only 0.3% of total garbage by weight. This study covered numerous vessels and was used by the NAS in their estimates (NAS 1975). In 1988, however, the Navy found that the plastics share of total garbage weight had risen to 6.7%--an apparent twentyfold increase. It must be noted that the more recent study is based on an analysis of a single Navy vessel operating over a short (32-h) cruise. Thus, the figures may not be representative.

In reviewing the data from the Navy studies, the question of potential differences in plastics usage between Navy and other vessels arises. Navy vessels carry extensive electronic equipment on board which may be wrapped in plastic "bubble" wrap and other cushioning materials. This source of

Table 2.--Summary of MARPOL Annex V restrictions (International Maritime Organization 1987).

Garbage type	All vessels: Outside special areas[a]	All vessels: Within special areas[a]	Offshore platforms and associated vessels[b]
Plastics	Disposal prohibited	Disposal prohibited	Disposal prohibited
Floating dunnage, lining and packing materials	>25 nmi from land	Disposal prohibited	Disposal prohibited
Paper, rags, glass, etc., not ground	>12 nmi from land	Disposal prohibited	Disposal prohibited
Paper, rags, glass, etc., ground[c]	>3 nmi from land	Disposal prohibited	Disposal prohibited
Food waste, not ground	>12 nmi from land	Disposal prohibited	Disposal prohibited
Food waste, ground[c]	>3 nmi from land	>12 nmi from land	>12 nmi from land
Mixed refuse types	(d)	(d)	(d)

[a]Annex V special areas include the Mediterranean, Baltic, Red, and Black Seas, and the Persian Gulf Areas.

[b]Offshore platforms and associated vessels include all fixed or floating platforms engaged in exploration or exploitation and associated offshore processing of seabed mineral resources, and all vessels alongside or within 500 m of such platforms.

[c]Ground waste must be able to pass through a screen with mesh size no larger than 25 mm (0.1 in).

[d]When garbage is mixed with other harmful substances having different disposal or discharge requirements, the more stringent disposal requirements shall apply.

plastics is not generally present on board other types of vessels. Second, considerably more at-sea repair occurs on board Navy ships than aboard merchant marine or fishing vessels. Tools and replacement parts may be packaged in plastic, and parts themselves may be plastic. Wire and cable have plastic insulation. On the other hand, due to the large crew sizes, food supplies on board Navy vessels are generally purchased in bulk. The reduced packaging associated with this bulk purchasing would suggest smaller plastic generation rate. Navy vessels may, therefore, generate more plastics from operational sources, but less from galley refuse.

In the absence of any conclusive evidence on the amount of plastics contained in the ship's waste stream, the results from the most recent Navy study (Koss and Mullenhard, pers. commun. 1988) have been used. This study indicates that plastics represent 6.7% of all wet and dry solid waste, and 11.3% of dry solid waste, by weight. Additional studies of this nature relative to shipping and other maritime sectors would certainly be welcome.

Garbage Densities

Further analysis of garbage generation patterns requires estimates of the density of garbage. These are needed in order to convert the weight of a given accumulation of garbage to volume terms. At sea, it may be the volume of garbage, rather than its weight, that figures in decisions regarding disposal options.

Table 3 shows estimates of garbage density for shipboard types of garbage. It will be noted that no sources of data specific to plastics were identified. Studies done for the State of New York by Franklin Associates (V. Sellers, Franklin Associates, pers. commun. 1988) found that 1,000 kg (2,200 lb) of uncompressed plastic soda containers had an average volume of 20.8 m^3 (325 ft^3), suggesting a density of 48.1 kg/m^3 (3.07 lb/ft^3). Navy officials, however, have suggested that a much lower density of 15.4 kg/m^3 (1 lb/ft^3) is appropriate (Koss and Mullenhard, pers. commun. 1988). This would imply that plastics used on board ship weigh one-third as much as much as empty soda bottles--an apparently generous volume estimate. In the absence of any data specific to ships, however, the Navy's estimate of 15.4 kg/m^3 (1 lb/ft^3) is incorporated. Again, this estimate is the more generous of those available in terms of estimating the volume of plastics generated on board.

Table 3.--Estimates of density for shipboard-generated garbage.

	Density	
Source of estimate and garbage type	kg/m^3	lb/ft^3
Society of Naval Architects and Marine Engineers (1982):		
Dry rubbish	100.0	6.3
Dry garbage	120.0	7.5
Refuse, 70% wet	640.0	40.0
Food waste	400 to 1,000	25.0 to 68.8
Gassan (1978):		
Hotel solids	277.0	17.2

Table 4 summarizes the numerous estimates and assumptions used in calculating garbage weights and volumes. The reader should note that densities are calculated for each of the different components of mixed garbage. Any conversions from garbage weight to volume made in this study must be considered, therefore, in the context of the density values used.

GARBAGE HANDLING AND DISPOSAL PRACTICES BEFORE AND AFTER MARPOL ANNEX V

This section summarizes the more substantial review of garbage handling and disposal practices contained in ERG (1988b). Estimates of the percentage of vessels using each of the various garbage handling and disposal methods, both historically and under Annex V, are used to evaluate the disposition of the aggregate garbage quantities under pre- and post-Annex V assumptions.

Pre-Annex V Garbage Handling and Disposal Practices

The historical methods employed by shipboard crews to dispose of garbage provide a basis for determining the current disposition of the garbage generated on board, i.e., how much is discarded overboard, how much brought back to shore for disposal, and how much is burned in onboard incinerators.

In most sectors, garbage handling practices vary depending on where the ship operates. Over deep-sea routes, garbage is typically collected throughout the ship and discharged daily. Closer to shore, crews are more likely to retain garbage for onshore disposal. The historical practice of ocean dumping while out at sea has been confirmed in most sectors. A representative of the American Institute of Merchant Shipping, for instance, states that: "Generally aboard merchant vessels on the high seas, waste generated as a result of vessel operations and deck maintenance is disposed of directly overboard" (Corrado 1986).

The predominance of ocean disposal is also indicated by statistics kept by the Department of Agriculture's Animal and Plant Health Inspection Service (APHIS). This agency requires ships entering the United States from foreign ports to incinerate, sterilize, or otherwise sanitize any garbage prior to disposing of it on shore. The APHIS inspection records for fiscal year 1986, for example, show that only 2.5% of vessels entering the United States from foreign ports off-loaded any garbage (A. Langston, U.S. Department of Agriculture, pers. commun. 1988).

Most commercial fishing groups also acknowledge that garbage dumping has traditionally been the most widely used means of getting rid of any trash which accumulates.

The use of garbage handling equipment such as grinders, compactors, or incinerators has not been widespread in the maritime sectors. Only some newer ships are equipped with such equipment. Until now, overboard disposal while well out at sea has been the most convenient and inexpensive method available. Based on discussions with operators in the merchant

Table 4.--Assumptions and estimates used in garbage generation calculations.

Domestic garbage generation rates (International Maritime Organization 1987)

Vessel category	Per capita per day kg	Per capita per day lb
Oceangoing	2.0	4.4
Coastal	1.5	3.3
Inland/harbor	1.0	2.2
Passenger cruise	2.4	5.3

Fishing waste generations rates (Eastern Research Group estimates)

Vessel category	Per vessel per day m^3	kg	ft^3	lb
Normal vessels	0.004	0.064	0.140	0.140
Longliners, etc.	0.008	0.127	0.280	0.280

Domestic waste components, by weight (Koss and Mullenhard, pers. commun. 1988)

Garbage type	As percent of all garbage by weight	As percent of dry garbage by weight
Wet (food waste)	40.6	--
Dry (nonfood waste)	59.4	100.0
Plastic	6.7	11.3
Glass	4.1	6.9
Metal	13.0	21.9
Rubber	0.3	0.5
Paper, other	35.2	59.3

Garbage density (Society of Naval Architects and Marine Engineers 1982), except for plastic density, which was suggested by Navy personnel

Garbage type	kg/m^3	m^3/kg	lb/ft^3	ft^3/lb
Total garbage	174.2	0.006	10.89	0.10
Dry garbage	100.0	0.010	6.30	0.16
Food waste	640.0	0.002	40.00	0.03
Plastics	16.0	0.063	1.00	1.00

marine, commercial fishing, and government sectors, it is assumed here that for most ships, overboard disposal is the predominant method used.

Vessels which spend more time operating close to shore are less likely to rely on overboard disposal. There are several possible reasons for this: Laws and regulations may already prohibit dumping in such areas; vessels are away from port for shorter periods and thereby generate less garbage; or operators may be conscious about dumping close to shore. Several categories of vessels have been identified as using alternative disposal means. These include segments of the coastal trade fleet, tug and towboat operators, recreational boaters, offshore oil and gas operations, some industrial and research vessels, and some Coast Guard vessels.

Post-Annex V Garbage Handling and Disposal Practices

Under MARPOL Annex V, vessel operators may have to implement changes in garbage handling procedures in order to achieve compliance with the requirements of the regulations. The actions taken by an individual operator will depend upon a number of factors, including (1) where the vessel operates and the specific restrictions of Annex V which apply in those areas, (2) the quantities and types of garbage generated by each vessel, and (3) the cost and noncost factors which influence the selection of compliance methods.

Each vessel owner or operator will evaluate his operations relative to the requirements of MARPOL Annex V. Table 2 presented a summary of the restrictions introduced by Annex V for the various types of garbage. Disposal of plastics is prohibited everywhere, and disposal of other types of wastes is restricted for vessels operating near shore. Vessels operating in special areas are prohibited from disposing of anything except food wastes, and then only beyond 12 mi from shore. A separate set of rules apply to offshore oil and gas operations.

Alternative compliance options have been analyzed in terms of their relative costs and conveniences in the regulatory analysis prepared for the Coast Guard (ERG 1988b). Among the compliance methods examined were: substitution of plastics, storage of garbage for onshore disposal, use of compactors to reduce garbage volumes, with subsequent disposal on shore, and installation of onboard garbage incinerators. The model used for comparing these alternatives took into account all of the relevant costs associated with each option, including the volumes and types of garbage generated; equipment, installation, and operating costs; the opportunity costs of current garbage handling and disposal procedures (i.e., not paying crews to dump garbage); and costs associated with off-loading and disposing of garbage in port.

The cost comparison model shows that for most vessels, onboard separation and storage of plastic garbage, with eventual disposal in port, is the least costly alternative (see ERG 1988b). As the garbage generation tables below will show, the quantities of plastics generated by most vessels would not present extreme storage difficulties. Where garbage volumes may cause inconveniences or storage problems, compactors can be used to reduce the volumes.

Several factors not captured by the cost comparison may steer vessel operators towards more costly compliance methods. If, for whatever reason, vessels anticipate the accumulation of large quantities of garbage on board, they may consider methods that reduce or eliminate this burden, even if it increases their costs. Operators may be concerned about situations where onshore garbage disposal would not be possible for extended periods of time, due to delays or the inability to obtain removal service in port. Finally, the cost comparisons do not consider issues caused by operations in special areas, where additional restrictions on the disposal of garbage will apply.

When both the cost and noncost issues are considered, most smaller vessels are still projected to choose separation and storage of garbage which they will no longer be able to dump overboard. Extensive use of onboard garbage compaction equipment is forecast, however, for larger commercial fishing vessels and for a majority of domestic trade merchant ships. Such equipment will be used to reduce the volume of garbage retained on board and to facilitate handling and disposal in port. Equipment manufacturers indicate that equipment suitable for onboard use can achieve a compaction ratio of between 500 and 1,000%, although for pure plastics the ratio is lower unless the material is first shredded. Only ships in the merchant shipping foreign trade category and some larger research and passenger ships are expected to select onboard incinerators. In the case of foreign trade vessels, the decision to invest in incinerators will not be based simply on economics, as incinerators represent the most expensive means of compliance, but rather upon the increased convenience afforded to the vessel. Time spent in port is extremely costly, thus incinerators may be viewed as "insurance" against the possibility of being delayed due to difficulties in obtaining garbage disposal services. It must be noted, however, that current or future air pollution standards for marine incinerators could greatly increase the cost of this option.

Special mention should be made of the solution expected to be adopted by U.S. Navy ships. As shown below, the Navy has particular garbage disposal problems due to the large number of crewmen on board. According to the most recent reports, Navy ships are expected to be outfitted with thermal extrusion equipment specially designed for shipboard application. This technology will enable Navy crews to melt down all plastics generated on board and extrude them into a storable form.

Pre- and Post-Annex V Garbage Disposition

Table 5 presents estimates of the pre- and post-Annex V distribution of vessels in the merchant shipping sector according to the garbage handling and disposal practices used. The distributions reflect ERG conclusions from the review of disposal practices and options described above. Similar distributions have been developed for each of the maritime sectors under study, but are not shown here.

Aggregate quantities of domestic garbage derived in the supporting statistical section are shown in the first column of Table 6 below. The table shows the pre- and post-Annex V disposition of these garbage

Table 5.--Current garbage handling and disposal practices and projected practices under MARPOL Annex V merchant shipping sector (Eastern Research Group estimates).

Merchant shipping	Current compliance rate (%)	Current compliance choices (%)				Annex V compliance choices (%)		
		Dump	Store	Compact	Incinerate	Store[a]	Compact	Incinerate
Foreign trade								
U.S. vessels								
Atlantic/Gulf/Pacific ports	5	95	0	0	5	5	70	25
Noncontiguous ports	5	95	0	0	5	5	70	25
Foreign vessels								
Atlantic/Gulf/Pacific ports	5	95	0	0	5	5	70	25
Noncontiguous ports	5	95	0	0	5	5	70	25
Noncontiguous trade	5	95	0	0	5	5	80	15
Great Lakes vessels								
1,000 GT and over	100	0	25	50	25	25	50	25
Under 1,000 GT	100	0	25	50	25	25	50	25
Military Sealift Command charter	5	95	0	0	5	5	75	20
Temporarily inactive vessels	5	95	0	0	5	5	75	20
Coastal shipping								
Ships								
1,000 GT and over	25	60	40	0	0	10	75	15
Under 1,000 GT	5	95	5	0	0	15	75	10
Tow/tugboats								
Large (inspected)	20	80	20	0	0	50	45	5
Small	20	80	20	0	0	60	40	0

[a]Refers to storage of all garbage that vessels would not be permitted to dump. Assumes other garbage will be dumped where allowed under Annex V.

Table 6.--Final disposition of vessel-generated domestic waste, aggregated sector totals (annual quantities) (GT = gross tons; MT = metric tons).

Maritime sector	Total generated annually (MT)	Pre-Annex V: Off-loaded in port (MT)	Pre-Annex V: Off-loaded in port (m^3)[a]	Pre-Annex V: Incinerated at sea (MT)	Pre-Annex V: Incinerated at sea (m^3)[a]	Pre-Annex V: Dumped overboard (MT)	Pre-Annex V: Dumped overboard (m^3)[a]
Merchant shipping	30,949	3,302	39,794	1,148	14,971	26,499	349,304
Commercial passenger vessels	258,074	232,121	3,026,799	638	8,322	25,315	330,095
Commercial fishing	233,177	0	0	0	0	233,177	3,040,564
Recreational boating	636,055	424,036	5,529,325	0	0	212,018	2,764,662
Offshore oil and gas operations	16,710	10,733	139,958	0	0	5,977	18,656
Miscellaneous vessel classes	1,637	5	60	0	0	1,633	20,778
U.S. Navy	57,596	0	0	0	0	57,596	751,040
U.S. Coast Guard	4,317	1,452	28,786	0	0	2,864	8,941
U.S. Army	490	0	0	0	0	490	6,388
NOAA	317	7	165	88	1,146	222	2,463
Total	1,239,322	671,656	8,764,887	1,874	24,439	565,791	7,292,892

Table 6.--Continued.

Maritime sector	Post-Annex V[b]							
	Off-loaded in port				Incinerated at sea		Dumped overboard	
	Plastics		Other					
	(MT)	(m^3)[a]	(MT)	(m^3)[a]	(MT)	(m^3)[a]	(MT)	(m^3)[a]
Merchant shipping	1,626	311,353	2,737	6,255	4,381	57,132	22,204	103,685
Commercial passenger vessels	22,490	2,304,400	233,340	1,060,557	1,117	14,564	1,128	5,265
Commercial fishing	15,373	1,352,768	0	0	3,723	48,542	214,081	999,660
Recreational boating	39,848	4,975,109	554,892	2,771,045	0	0	41,315	128,964
Offshore oil and gas operations	398	49,740	5,547	72,799	0	0	0	0
Miscellaneous vessel classes	109	5,372	0	0	306	3,986	1,223	5,709
U.S. Navy	3,859	2,409,124	0	0	0	0	53,737	250,929
U.S. Coast Guard	289	126,913	765	2,604	0	0	3,262	10,183
U.S. Army	33	9,143	0	0	0	0	199	621
NOAA	11	331	0	0	148	1,926	158	737
Total	84,037	11,544,253	797,282	3,913,261	9,674	126,150	337,306	1,505,752

[a]Weight-to-volume conversions reflect (1) the densities of the various types of garbage (see Table 4), (2) the composition of the vessel waste stream, and (3) the degree to which compaction equipment is used in each sector.

[b]Assumes full compliance with Annex V requirements.

quantities. Both the weight and volume of garbage are indicated. Weight-to-volume conversions reflect assumptions about the types of garbage generated and the use of compaction to reduce garbage volume. This table shows aggregated sector totals only. A set of more detailed disposition tables is found in the Appendix.

The first columns of Table 6 indicate the current disposition of vessel-generated domestic garbage. The relative quantities of garbage currently brought back to shore, incinerated, or dumped overboard vary from sector to sector. A small amount of at-sea incineration occurs in portions of the merchant shipping and cruise ship sectors as well as on some National Oceanic and Atmospheric Administration (NOAA) research vessels. The percentage of domestic garbage brought back to shore for disposal is relatively high in the commercial passenger and recreational boating sector. Of the 1.2 million metric tons (MT) generated in all of the sectors, however, 566,000 MT or 45% by weight is still dumped overboard.

Under Annex V, some increased use of marine incinerators will occur, but the percentage of domestic garbage disposed of via incineration at sea will remain below 1%. All plastics, with the exception of that destroyed in incinerators, will be returned to shore for disposal. The current methodology predicts that 84,037 MT of plastics will be brought ashore for disposal. This will account for only 9.5% of all garbage brought ashore on a tonnage basis. Because of its low density, however, in volume terms plastics will represent close to 75% of the waste. Restrictions on the disposal of other types of garbage for vessels operating close to shore or in special areas will also increase the quantity of nonplastics brought ashore. Overall, the net increase in plastics and nonplastics brought ashore under Annex V will be 209,663 MT.

SUPPORTING STATISTICAL ANALYSIS OF MARITIME SECTORS SUBJECT TO COAST GUARD ENFORCEMENT OF MARPOL ANNEX V REGULATIONS

This section provides supporting data on the populations of ships covered in this study and used to generate the estimates of aggregate garbage generation shown in Table 6. Seven separate maritime sectors are identified as falling under the jurisdiction of the Coast Guard under MARPOL Annex V. These sectors are: merchant shipping, commercial fishing, commercial passenger vessels, recreational boating, offshore oil and gas operations, research and other miscellaneous vessels, and vessels operated by the U.S. Government. Each of these is profiled below in terms of the number and types of ships, onboard employment, and the frequency and duration of voyages. This information is then combined with data from earlier sections to derive per voyage, per vessel, and aggregate annual garbage quantity estimates for each of the sectors.

Merchant Shipping

Merchant vessels are those ships involved in the waterborne transport of cargo and passengers over established transoceanic, coastwise, intercoastal, and inland water routes. Under the provisions of the Jones Act, domestic waterborne commerce (cargoes moving between U.S. ports) is reserved exclusively for U.S. vessels. The U.S. import and export trade, however, is dominated by foreign vessels. The foreign and domestic trade sectors are discussed separately below.

Foreign Trade Vessels

According to the U.S. Maritime Administration (MARAD), the U.S. oceangoing merchant fleet numbers approximately 823 vessels of 1,000 gross tons (GT) and over. Of these, however, some 391 are inactive. Of the 432 active U.S. vessels, 122 or 28% are active in foreign trade. Another 54 vessels are active in Marine Sealift Command (MSC) operations, and will have voyage patterns comparable to foreign trade ships (see Table 7).

In addition to the vessels covered by MARAD, the Coast Guard's Marine Safety Information System (MSIS) data base shows there to be 43 vessels under 1,000 GT that are certificated for operation over open ocean routes. Thus, a total of 219 U.S.-flagged vessels operate over foreign trade routes.

The MARAD reports show that foreign-flagged vessels dominate the foreign trade sector, accounting for 95.6% of all U.S. import and export trade by tonnage (MARAD 1987b). The number of foreign vessels involved is commensurate. Data from the Coast Guard indicate that in 1987 a total of 6,751 foreign vessels, representing 110 different shipping nations, were inspected at U.S. ports (Coast Guard 1987b).

We assumed that vessels without incinerators will off-load all garbage in their final foreign port of call prior to setting sail for the United States. Under this assumption, vessels will retain on board all garbage they are prevented from dumping, and seek to off-load it upon return to the United States.

In order to estimate how much garbage is generated by these ships while en route to the United States, we examined data from the U.S. Customs Bureau's AE-975 file, Vessel Entrances and Clearances (U.S. Bureau of the Census 1987). This data base includes information on the final foreign port of call of vessels arriving at U.S. ports.

Four months of data (January, April, July, and October) were examined and used to derive annual estimates. In 1987, U.S. vessels made a total of 3,969 entrances to U.S. ports, while an estimated 33,087 entrances were made by foreign vessels. Table 8 shows a breakdown of these entrances by U.S. coastal area and foreign region of origin. Along the Atlantic and Gulf coasts, the largest number of entrances, 55 and 40%, respectively, were recorded by vessels clearing Customs from Caribbean ports. Entrances at Pacific coast ports were dominated by vessels arriving from Pacific Rim countries (46.6%) and from Pacific Canadian ports (28.8%).

A weighted average voyage length for foreign trade vessels arriving at U.S. ports was developed by calculating typical voyage lengths for each of the U.S.-foreign region pairings from Table 8. The estimated voyage lengths are based upon representative voyages from each foreign region to the U.S. coast and an assumed vessel speed of approximately 500 nmi per

Table 7.--Deployment status of U.S. flag merchant fleet, vessels 1,000 gross tons (GT) and over (U.S. Maritime Administration (MARAD), Merchant Marine Data Sheet, 1 March 1987).

Deployment status	Passenger/ combination		General cargo		Intermodel vessels		Bulk carriers		Tankers		Total	
	No.	Dwt	No.	Dwt	No.	Dwt	No.	Dwt	No.	Dwt	No.	Dwt
Active vessels												
Privately owned	2	15	36	531	112	2,694	22	934	192	11,772	364	15,946
Oceangoing												
U.S. foreign trade	--	--	26	380	69	1,703	13	684	14	806	122	3,573
Foreign-to-foreign	--	--	--	--	4	72	--	--	8	571	12	643
Domestic trade	2	15	1	18	20	358	7	188	146	9,671	176	10,250
Coastal	--	--	--	--	1	17	5	133	97	4,062	103	4,212
Noncontiguous	2	15	1	18	19	341	2	55	49	5,609	73	6,038
Military Sealift Command charter	--	--	9	133	19	561	2	62	24	724	54	1,480
Great Lakes[a]	--	--	--	--	--	--	55	1,819	3	20	58	1,840
Government-owned	4	32	3	26	--	--	--	--	1	17	8	75
BB charter and other custody	4	32	3	26	--	--	--	--	1	17	8	75
Subtotal--active fleet	6	47	39	557	112	2,694	22	934	193	11,789	372	16,021
Inactive vessels												
Privately owned	6	59	13	164	35	1,124	39	937	33	3,040	126	5,324
Oceangoing	6	59	13	164	35	1,124	4	336	33	3,040	91	4,723
Temporarily inactive	--	--	3	43	1	33	1	63	2	131	7	270
Laid up	6	59	7	82	32	1,085	3	273	29	2,841	77	4,340
Laid up (MARAD custody)	--	--	3	39	2	6	--	--	2	68	7	113
Great Lakes	--	--	--	--	--	--	35	601	--	--	35	601

Table 7.--Continued.

Deployment status	Passenger/ combination		General cargo		Intermodel vessels		Bulk carriers		Tankers		Total	
	No.	Dwt	No.	Dwt	No.	Dwt	No.	Dwt	No.	Dwt	No.	Dwt
Government-owned (MARAD)	24	183	184	2,102	28	761	--	--	21	623	257	3,669
National defense												
Reserve fleet	21	166	184	2,102	23	593	--	--	18	401	246	3,262
Ready research force (RRF)	1	9	53	661	17	438	--	--	8	141	79	1,249
Other reserve	6	57	122	1,356	6	155	--	--	9	244	143	1,812
Special programs	1	5	3	28	--	--	--	--	--	--	4	33
Nonretention	13	95	6	57	--	--	--	--	1	16	20	168
In processing for RRF	--	--	--	--	4	152	--	--	--	--	4	152
Other government-owned	3	17	--	--	1	16	--	--	3	222	7	255
Subtotal--Inactive fleet	30	242	197	2,266	63	1,885	39	937	54	3,663	383	8,993
Total--Active and inactive	36	289	236	2,823	175	4,579	61	1,871	247	15,452	755	25,014

[a]Includes ships normally active but laid up due to the winter freeze.

Table 8.--Entrances to U.S. ports by U.S. and foreign vessels, and estimated days at sea by U.S. coastal area, 1987 (U.S. Bureau of the Census 1987; Eastern Research Group estimates).

U.S. coastal area	Vessel origin	Estimated number of entrances: Foreign vessels	U.S. vessels	Total vessels	Estimated voyage length[a] (days)
Atlantic	Caribbean	5,895	954	6,849	3
	Scandinavia and N. Europe	1,497	204	1,701	9
	Canada--Atlantic	963	3	966	3
	Mediterranean	765	45	810	9
	W. coast S. America	612	27	639	9
	E. coast S. America	465	36	501	8
	Pacific Rim	282	3	285	15
	W. coast Africa	267	9	276	11
	Australasia	126	--	126	17
	Indonesia and India	123	--	123	16
	Middle East	78	6	84	12
	E. coast Africa	39	9	48	16
	Canada--Great Lakes	39	--	39	4
	Total	11,151	1,296	12,447	
	Weighted average voyage length	5.7	4.6		
Gulf	Caribbean	3,264	474	3,738	3
	W. coast S. America	1,794	249	2,043	6
	Scandinavia and N. Europe	1,212	51	1,263	10
	Mediterranean	645	42	687	10
	Pacific Rim	435	9	444	13
	W. coast Africa	327	27	354	15
	E. coast S. America	267	15	282	8
	Canada--Atlantic	282	--	282	6
	Australasia	99	--	99	14
	Indonesia and India	72	3	75	13
	Middle East	63	3	66	12
	E. coast Africa	27	9	36	10
	Canada--Great Lakes	33	--	33	7
	Canada--Pacific	3	--	3	7
	Total	8,523	882	9,405	
	Weighted average voyage length	6.7	5.3		
Pacific	Pacific Rim	3,285	306	3,591	11
	Canada--Pacific	1,650	567	2,217	3
	Caribbean	708	195	903	10
	W. coast S. America	321	138	459	15

Table 8.--Continued.

U.S. coastal area	Vessel origin	Estimated number of entrances: Foreign vessels	U.S. vessels	Total vessels	Estimated voyage length[a] (days)
	Australasia	174	3	177	11
	Indonesia and India	150	15	165	15
	Scandinavia and N. Europe	120	3	123	15
	E. coast Africa	51	--	51	11
	Mediterranean	12	--	12	18
	Total	6,471	1,227	7,698	
	Weighted average voyage length	9.2	7.7		
Great Lakes	Canada--Great Lakes	1,716	156	1,872	1
	Scandinavia and N. Europe	96	9	105	10
	Mediterranean	27	--	27	10
	W. coast Africa	12	--	12	11
	Pacific Rim	6	--	6	16
	Middle East	3	--	3	13
	Total	1,860	165	2,025	
	Weighted average voyage length	1.7	1.5		
Noncontiguous areas (includes Alaska, Hawaii Puerto Rico, and Virgin Islands	Caribbean	3,891	354	4,245	(b)
	Pacific Rim	426	6	432	(b)
	W. coast S. America	195	27	222	(b)
	E. coast S. America	135	3	138	(b)
	Scandinavia and N. Europe	93	--	93	(b)
	Australasia	84	--	84	(b)
	Indonesia and India	75	6	81	(b)
	W. coast Africa	60	3	63	(b)
	Canada--Atlantic	54	--	54	(b)
	E. coast Africa	42	--	42	(b)
	Mediterranean	18	--	18	(b)
	Canada--Pacific	6	--	6	(b)
	Middle East	3	--	3	(b)
	Total	5,082	399	5,481	(b)

[a]The percentage of entrances from each vessel origin is used to derive the weighted average voyage lengths for each coastal area.

[b]Voyage lengths for entrances to noncontiguous ports are estimated as follows: Hawaii--6 days (60% of entrances are from Japan), Puerto Rico and the Virgin Islands--1 day (majority of entrances are from Caribbean countries).

As indicated above, the Jones Act excludes foreign vessels from competing for U.S. domestic trade. Consequently, all domestic trade moves aboard U.S. vessels. In 1987, the fleet of U.S.-flagged domestic trade vessels included the following:

- 176 vessels of 1,000 GT and over (MARAD 1987a). Of these, 103 or 59% are active in "coastal" trade or trade between ports in the contiguous United States (see Table 7). All but six of these are tankers. The remaining 73 vessels operate in "noncontiguous" trade or trade between the contiguous U.S. states and the noncontiguous states and properties. Included in this total are 49 tankers and 19 intermodal vessels, as well as 2 U.S. cruise ships (described in the next section);

- 12 freighters and 14 tankers under 1,000 GT designated for coastwise travel (Coast Guard 1987b);

- 14 freighters and 43 tankers designated for lakes, bays, and sounds operation (Coast Guard 1987b);

- 9 freighters and 6 tankers designated for river operation (Coast Guard 1987b); and

- ca. 5,000 tug and towboats (U.S. Army Corps of Engineers 1987), which operate predominantly over the inland waterways.

Great Lakes ships may operate in either domestic or foreign (United States-Canada) trade. No breakdown is reported for these ships based on trade status, hence they are analyzed in terms of the number of ships and annual operating ratios, rather than number of entrances. (Operating ratios or utilization rates refer to the percentage of days annually on which the ship is engaged in trading activities.) In 1987, there were estimated to be 58 active Great Lakes ships of 1,000 GT or over (MARAD 1987a) and 7 of under 1,000 GT (Coast Guard 1987b).

Domestic trade vessels operate exclusively within U.S. waters, and will hence be under Coast Guard jurisdiction whenever they are operating. One exception is noncontiguous vessels which may exit U.S. waters en route from the continental United States. The approach to estimating garbage quantities in the domestic sector is, therefore, somewhat different. Whereas the annual garbage quantities generated by foreign trade vessels are estimated based upon the number of voyages, in this case it is the number of ships, the crew size, and the annual ship utilization rate which are the determinants.

Crews aboard domestic trade ships also average 20-25 men. Large oceangoing tugs carry up to 10 men, while smaller tugs and motor barges carry 6-man crews.

Domestic ships over 1,000 GT are estimated to have average voyage lengths of 5 days, while those under 1,000 GT average 4 days. Trips of large tugboats are also assumed to average 4 days, while small tugs are estimated to average 2 days at sea.

All vessels in the merchant marine sector, with the exception of Great Lakes ships, are assumed to operate with 90% utilization rates. Due to the winter freeze-up, Great Lakes ships are limited to approximately 50% utilization.

Garbage Generation Estimates

Domestic garbage.--In Table 9 below, estimates of the amount and types of garbage generated over typical voyages are shown for each of the merchant shipping categories. The table shows both weight and volume estimates, and indicates that the greatest accumulation would occur on foreign trade and large domestic trade ships. Over a 7-day voyage these ships are estimated to generate 330 kg or 2.2 m^3 of garbage, of which only 22 kg is plastics. One cubic meter represents approximately 8-9 large 113.5 liter (30-gal) garbage bags.

Cargo wastes.--Table 10 presents estimates of the number of entrances to U.S. ports by U.S. and foreign general cargo vessels, and of the quantities and types of dunnage generated by such ships. In the Customs data base, dry cargo ships account for 56.1% of entrances by U.S. ships and 74.4% of entrances by foreign ships (Bureau of the Census 1987). The MARAD data indicate that 28 of the 101 dry cargo ships in the U.S. foreign trade fleet (27.7%) are general cargo-type ships (MARAD 1987a). Applying this percentage to the number of dry cargo entrances, it is estimated that U.S. and foreign break-bulk ships enter U.S. ports 617 (0.277 × 0.561 × 3,969 entrances) and 6,819 (0.277 × 0.744 × 33,087 entrances) times annually. These entrances are seen in Table 10 to generate potentially close to 20,000 m^3 of waste lumber, 3,815 m^3 of cardboard, and 2,981 m^3 of plastic.

Commercial Passenger Vessels

The category of commercial passenger vessels encompasses all for-hire passenger-carrying vessels, including cruise ships, ferries and excursion vessels, and charter boats.

Cruise Ships

The cruise ship category includes domestic ships which operate exclusively within U.S. waters and foreign ships which sail from U.S. ports on international voyages. The Customs data base identifies approximately 80 foreign cruise ships which operate regularly out of U.S. ports. In 1986, these vessels recorded an estimated 3,324 entrances to U.S. ports (see Table 11). A high proportion of these entrances (45%) was recorded by vessels entering the Miami and Tampa port districts from the Bahama Islands. Other origin and destination combinations which account for large numbers of entrances include Canada/Alaska, Mexico/Los Angeles, Mexico/Miami, and Bermuda/New York. Puerto Rico and the Virgin Islands also receive numerous cruise ships, which arrive primarily from other Caribbean or South American ports.

Based upon the predominance of short-haul trips represented by these data, an average voyage duration of 1 day (24 h) is assumed for cruise

Table 9.--Derivation of per voyage, per vessel, and annual domestic garbage quantities generated merchant shipping (Eastern Research Group estimates) (GT = gross tons, MT = metric tons).

Merchant shipping	Voyage length (days)	Crew size	Person days per voyage	Per capita generation rate (kg/day)	Domestic garbage generation per voyage[a]: Total garbage (kg)	Total garbage (m^3)	Dry garbage (kg)	Dry garbage (m^3)	Plastic garbage (kg)	Plastic garbage (m^3)	Annual ship utilization rate[c] (%)	Voyages per year	Garbage per year per vessel (kg)	No. of vessels	No. of entrances	Total garbage per year[b] (MT)	Total garbage per year[b] (m^3)
Foreign trade																	
U.S. vessels																	
Atlantic/Gulf/Pacific	7	25	165	2.0	330	2	196	2	22	1	90	50	16,425	NA	3,405	1,124	7,326
Noncontiguous/foreign	2	25	53	2.0	105	1	62	1	7	0	90	156	16,425	NA	399	42	273
Foreign vessels																	
Atlantic/Gulf/Pacific	7	25	173	2.0	345	2	205	2	23	1	90	48	16,425	NA	26,145	9,020	58,809
Noncontiguous/Great Lakes	2	25	60	2.0	120	1	71	1	8	1	90	137	16,425	NA	6,942	833	5,431
Noncontiguous trade (U.S.--domestic)	7	25	175	2.0	350	2	208	2	23	1	90	47	16,425	71	NA	1,166	7,603
Great Lakes (domestic and foreign trade)																	
1,000 GT and over	2	25	53	1.5	79	1	47	0	5	0	50	87	6,844	58	NA	397	2,588
Under 1,000 GT	2	25	53	1.5	79	1	47	0	5	0	50	87	6,844	7	NA	48	312
United States																	
Military Sealift charter	7	25	175	2.0	350	2	208	2	23	1	90	47	16,425	54	NA	887	5,783
Temporarily inactive vessels	7	25	175	2.0	350	2	208	2	23	1	90	47	16,425	7	NA	115	750
Coastal shipping																	
Ships																	
1,000 GT and over	5	25	125	1.5	188	1	111	1	13	1	90	66	12,319	103	NA	1,269	8,273
Under 1,000 GT	4	25	100	1.5	150	1	89	1	10	1	90	82	12,319	98	NA	1,207	7,871
Tow/tugboats																	
Large (inspected)	4	10	40	1.5	60	0	36	0	4	0	90	82	4,928	12	NA	59	386
Small	2	6	12	1.5	18	0	11	0	1	0	90	164	2,957	5,000	NA	14,783	96,380
Total garbage per year																30,949	201,785

[a]Dry garbage is calculated as 59.4% of total garbage by weight. Plastic garbage is 6.7% of dry garbage by weight. See Table 4.
[b]Total garbage weight per year is equal to the product of either (1) per vessel annual garbage quantity and the vessel population, or (2) garbage quantity per voyage and the number of entrances.
[c]Refers to the percentage of days annually operating in U.S. waters.

Table 10.--Estimates of annual quantities of cargo waste (dunnage) currently dumped and quantities dumped under MARPOL Annex V (Eastern Research Group estimates).

Basis of estimate	U.S. vessels	Foreign vessels
Number of entrances to U.S. ports per year	3,969	33,087
Dry cargo as percentage of all entrances	56.1%	74.4%
Dry cargo entrances	2,227	24,617
General cargo as percentage of all dry cargo ships	27.7%	27.7%
General cargo entrances	617	6,819
Dunnage generated per clearance from U.S. port		
Lumber		
Quantity (m^3)	48.6	48.6
Percent of entrances	66.7%	66.7%
Cardboard		
Quantity (m^3)	23.6	23.6
Percent of entrances	33.3%	33.3%
Plastic		
Quantity (m^3)	0.12	0.12
Percent of entrances	10.0%	10.0%
Total dunnage quantities generated per year		
Lumber (m^3)	19,983.4	220,930.2
Cardboard (m^3)	130,979	130,979
Plastic (m^3)	7.20	7.20
Incidence of dumping	50.0%	50.0%
Total dunnage quantities dumped in U.S. waters per year		
Current practice		
Lumber (m^3)	9,991.7	110,465.1
Cardboard (m^3)	1,768,214	1,768,214
Plastic (m^3)	3.602	3.602
Under MARPOL Annex V		
Lumber (m^3)	9,991.7	110,465.1
Cardboard (m^3)	1,768,214	1,768,214
Plastic (m^3)	0.00	0.00

Table 11.--Cruise ships entering U.S. ports (Bureau of the Census 1987; Eastern Research Group estimates).

Vessel origin	U.S. port of entrance	Estimated number of entrances (1987)	Percent of total
Bahamas	Miami	1,232	37.1
Bahamas	Tampa	276	8.3
Canada (Pacific coast)	Anchorage	244	7.3
Mexico (Pacific coast)	Los Angeles	228	6.9
Mexico (Gulf coast)	Miami	168	5.1
Bermuda	New York	152	4.6
French West Indies	Virgin Islands	116	3.5
Leeward/Windward Islands	Virgin Islands	84	2.5
Netherlands Antilles	Virgin Islands	80	2.4
French West Indies	San Juan, Puerto Rico	72	2.2
Netherland Antilles	Miami	72	2.2
Haiti	Miami	56	1.7
Netherland Antilles	San Juan, Puerto Rico	56	1.7
Bahamas	San Juan, Puerto Rico	52	1.6
Haiti	San Juan, Puerto Rico	44	1.3
Jamaica	Miami	44	1.3
Dominican Republic	Virgin Islands	40	1.2
Dominican Republic	San Juan, Puerto Rico	32	1.0
Venezuela	San Juan, Puerto Rico	32	1.0
All other origins	All other destinations	244	7.3
Total		3,324	100.0

ships arriving in the United States. While examples of much longer voyages may be found within the data, short voyages are much more typical.

Foreign cruise ships entered U.S. ports with an average passenger complement of 786. Crew-to-passenger ratios are approximately 1:2 (J. Ruers, International Committee of Passenger Liners, pers. commun. 1988), hence an average of approximately 1,000 persons are assumed to be on board such ships.

Coast Guard data indicate that approximately two dozen U.S.-flagged vessels are used in domestic cruise operations (L. Stanton, Coast Guard, pers. commun. 1988). These include two large vessels of over 1,000 GT which operate in the Hawaiian interisland trade as well as several smaller vessels active on coastal routes along both the east and west coasts. Average time between ports is estimated at 1 day, as the vessels are usually in port each night. Such vessels are estimated to carry an average of 200 passengers and crew members (E. Scharfe, Director, Small Passenger Vessel Association, pers. commun. 1988) during typical cruises.

Other Passenger-Carrying Vessels

Additional categories of passenger-carrying vessels include ferries and charter fishing and pleasure vessels, of which there are a large number. In 1987, the Coast Guard's MSIS data base contained some 49 U.S.-flagged passenger vessels of 1,000 GT and over, and 4,774 vessels under 1,000 GT.

Among the larger passenger vessels, four are ocean-designated and include the two Hawaiian cruise ships discussed above as well as two converted hospital ships that are part of the MSC. These are covered in the merchant vessel data. Ten larger passenger vessels operate with river designations (e.g., Mississippi River cruises), while the remaining 34 are designated for operation in lakes, bays, and sounds. These vessels offer ferrying services and excursion or sightseeing cruises of short duration. Thus, a total of 44 additional large ferries and riverboats operate domestically. They are assumed to carry up to 1,000 passengers on voyages averaging 1 day in duration.

Approximately 75% of the 4,774 passenger-carrying vessels under 1,000 GT are charter fishing boats, with ferries, yachts, and other small boats accounting for the remaining 25% (Stanton pers. commun. 1988). Charter fishing boats are assumed to carry an average of 20 persons, while ferries and other commercial passenger vessels are assumed to carry 200 people. Voyage lengths of 1 day or less are assumed for all vessels in this category.

Large cruise ships generate substantial quantities of garbage even on overnight voyages. Table 12 indicates that 1,000 passengers on a luxury cruise will generate over 2 MT of garbage each day. Smaller ships carrying 200 passengers may generate close to 500 kg per day.

Commercial Fishing

United States Vessels

Fishing vessels may be classified according to whether they operate in onshore, offshore, or inland fisheries. Onshore fishing, defined as fishing which takes place within 12 nmi from shore, is conducted by smaller boats making primarily day-long trips. Data sources distinguish between fishing boats, which are under 5 net tons in size, and fishing vessels, which include all craft of 5 net tons or more (see Table 13).

Boats under 5 net tons generally do not exceed 7.6 m (25 ft) in length (T. Willis, Coast Guard Documentation Branch, pers. commun. 1988), and are not eligible for Coast Guard documentation. Normally, therefore, they do not operate at significant distances from shore. For convenience, all fishing boats (i.e., <5 net tons) are assumed to operate in the onshore fisheries. The NMFS estimates there to be approximately 105,500 boats active in the U.S. fisheries (NMFS 1987). These are assumed to carry an average of three crew members, and to return to port each night.

Table 12.--Derivation of per voyage, per vessel, and annual domestic garbage quantities generated commercial passenger vessels (Eastern Research Group estimates) (GT = gross tons, MT = metric tons).

Commercial passenger ships	Voyage length (days)	Crew size	Person days per voyage	Per capita generation rate (kg/day)	Domestic garbage generation per voyage[a]: Total garbage (kg)	Total garbage (m^3)	Dry garbage (kg)	Dry garbage (m^3)	Plastic garbage (kg)	Plastic garbage (m^3)	Annual ship utilization rate[c] (%)	Voyages per year	Garbage per year per vessel (kg)	No. of vessels	No. of entrances	Total garbage per year[b] (MT)	Total garbage per year[b] (m^3)
Cruise ships																	
U.S. vessels																	
>1,000 GT	1	1,000	1,000	2.4	2,400	16	1,426	14	161	10	90	329	788,400	2	NA	1,577	10,281
Under 1,000 GT	1	200	200	2.4	480	3	285	3	32	2	90	329	157,680	24	NA	3,784	24,673
Foreign vessels	1	1,00	1,000	2.4	2,400	16	1,426	14	161	10	90	NA	NA	NA	3,324	7,978	52,013
Excursion vessels	1	200	200	2.4	480	2	285	3	32	2	90	329	157,680	1,194	NA	188,270	1,227,495
Charter boats	1	20	20	2.4	48	0	29	0	3	0	90	329	15,768	3,581	NA	56,465	368,148
Total garbage per year																258,074	1,682,608

[a]Dry garbage is calculated as 59.4% of total garbage by weight. Plastic garbage is 6.7% of dry garbage by weight. See Table 4.

[b]Total garbage weight per year is equal to the product of either (1) per vessel annual garbage quantity and the vessel population, or (2) garbage quantity per voyage and the number of entrances.

[c]Refers to the percentage of days annually operating in U.S. waters.

Table 13.--Employment and craft in the U.S. commercial fisheries ([U.S.] National Marine Fisheries Service 1987).

Size	Number
Vessel >5 tons	24,300
Motor boats	104,000
Other boats	1,500
Total craft	129,800
Fishermen	238,800

While some larger craft also operate close to shore, fishing vessels (5 net tons and over) are assumed to operate beyond 12 nmi from shore. These vessels are capable of longer voyages, and are frequently equipped with sophisticated navigational and fish locating equipment. They also have greater onboard storage and processing capacity.

The NMFS estimates that in 1986 there were 24,300 fishing vessels of 5 net tons or more in the United States. While these may range up to 1,000 GT and over in size, relatively few are this large. Table 14 indicates that over 60% of fishing vessels are both smaller than 25 net tons in size, and <15.2 m (50 ft) in length.

Inland fishing covers commercial activity taking place on the inland waterways. At present, small commercial fisheries operate on the Great Lakes and along the Mississippi River (S. Koplin, NMFS, Statistics Branch, pers. commun. 1988), and account for only a small percentage of the national catch. States bordering the Great Lakes, for example, accounted for only 1.7% of the 1987 U.S. commercial catch (NMFS 1987). As boats active in the inland fisheries will be contained within the data presented above, the craft involved will be assumed to operate in a fashion similar to those in the saltwater fisheries. Assumptions regarding crew sizes and voyage lengths of fishing vessels are shown in Table 15, which derives the per voyage, per vessel, and aggregate annual garbage quantities.

Foreign Fishing Vessels

Foreign fishing vessels granted access to fishing stocks within the U.S. exclusive economic zone (EEZ) will also be expected to comply with MARPOL Annex V. While some restrictions on vessel discharges already apply, the requirements do not address specifically the problem of garbage dumping.

In the recent past, foreign fishing activity in U.S. waters has centered around the eastern Bering Sea and Aleutian Islands areas, where

Table 14.--Documented U.S. fishing vessels,[a] by length and gross tonnage (U.S. Coast Guard, Marine Safety Information System 20 April 1986; [U.S.] National Marine Fisheries Service 1987).

	Vessel length				
Gross tonnage	<15.2 m (<50 ft)	15.2-19.8 m (50-65 ft)	19.8-24.1 m (65-79 ft)	>24.1 m (>79 ft)	Total
Less than 25	14,703	112	2	2	14,815
25-49	2,774	1,152	33	--	3,959
50-99	340	1,511	1,107	45	3,003
100-199	18	117	1,418	674	2,227
200-299	--	--	--	69	69
300-399	--	--	--	32	32
400-499	--	--	--	49	49
500-599	--	--	--	45	45
600-699	--	--	--	15	15
700-799	--	--	--	10	10
800-899	--	--	--	10	10
900-999	--	--	--	23	23
1,000-1,999	--	--	--	34	34
2,000-2,999	--	--	--	2	2
3,000-3,999	--	--	--	2	2
4,000-4,999	--	--	--	2	2
More than 5,000	--	--	--	--	--
Total	17,835	2,891	2,560	1,015	24,300

[a]Vessels are defined as craft of 5 net tons or over.

the most significant target species has been Alaskan pollock. The country most active in this fishery is Japan. Other fisheries with considerable foreign participation include the Pacific whiting and Atlantic mackerel fisheries.

Direct access to U.S. fishing stocks by foreign vessels has been cut back considerably in recent years. At present, foreign access is obtained primarily through joint venture permits (J. Kelley, NMFS, Office of Fishery Conservation and Management, pers. commun. 1989). Under joint venture agreements, U.S. vessels deliver their catch to large foreign motherships or other factory trawlers, which process the fish at sea.

Data on the number of foreign fishing vessel permits issued in 1987, by type of vessel, flag of vessel, and fishery, were requested from the NMFS, but were not available in time for this report. In general, though, activity by foreign fishing vessels within U.S. waters has been decreasing in recent years with the "Americanization" of the U.S. EEZ. Direct fishing

Table 15.--Derivation of per voyage, per vessel, and annual domestic garbage quantities generated: commercial fishing (Eastern Research Group estimates) (GT = gross tons, MT = metric tons).

Commercial fishing	Voyage length (days)	Crew size	Person days per voyage	Per capita generation rate (kg/day)	Domestic garbage generation per voyage[a]: Total garbage (kg)	Total garbage (m^3)	Dry garbage (kg)	Dry garbage (m^3)	Plastic garbage (kg)	Plastic garbage (m^3)	Annual ship utilization rate[c] (%)	Voyages per year	Garbage per year per vessel (kg)	No. of vessels	No. of entrances	Total garbage per year[b] (MT)	Total garbage per year[b] (m^3)
Undocumented	1	3	3	1.5	5	0	3	0	0	0	66	241	1,084	105,500	NA	114,367	745,660
Documented																	
5-25 GT	7	7	49	2.0	98	1	58	1	7	0	66	34	3,373	14,815	NA	49,965	325,766
25-300 GT	15	15	225	2.0	450	3	267	3	30	2	66	16	7,227	9,258	NA	66,908	436,229
300-1,000 GT	15	15	225	2.0	450	3	267	3	30	2	66	16	7,227	188	NA	1,359	8,858
Over 1,000 GT	30	30	900	2.0	1,800	12	1,069	11	121	8	66	8	14,454	40	NA	578	3,770
Foreign vessels[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0
Total garbage per year																233,177	1,520,282

[a]Dry garbage is calculated as 59.4% of total garbage by weight. Plastic garbage is 6.7% of dry garbage by weight. See Table 4.
[b]Total garbage weight per year is equal to the product of either (1) per vessel annual garbage quantity and the vessel population, or (2) garbage quantity per voyage and the number of entrances.
[c]Refers to the percentage of days annually operating in U.S. waters.

by foreign vessels has been almost completely phased out, while joint ventures between U.S. catcher vessels and foreign processing vessels are declining. More and more, foreign access to U.S. fishery products will be in the form of exported products processed on U.S. soil. According to a report to the Alaska Department of Environmental Conservation, "it is generally assumed that there will be little, if any, joint venture activity in the North Pacific EEZ by 1991" (Pacific Associates 1988).

Garbage Generation Estimates

Domestic garbage.--Table 15 shows the derivation of the per voyage and annual domestic waste estimates. The largest ships may generate up to 1,800 kg of garbage overall per voyage. Of this amount, however, they would likely have to retain only the plastics. Small fishing boats are estimated to generate only 4.5 kg of total garbage per day at sea.

Commercial wastes.--As indicated, it is assumed that most fishing craft will generate an additional 0.028 m^3 (1.0 ft^3) of plastic gear waste per week (0.004 m^3 (0.14 ft^3) per day). Longliners and boats in the herring fisheries are assumed to generate twice this amount. Such vessels are assumed to represent 5% of all vessels in the 5-25 and 25-300 GT categories. Table 16 shows the estimated quantities of fishing wastes generated annually.

Recreational Boating

All recreational boats operating over the navigable waters of the United States are also required to comply with Annex V. Potentially, therefore, most of the approximately 14 million recreational boats in the United States might be included in an analysis of Annex V. For this study, we limit the analysis to numbered boats in coastal states or in states bordering the Great Lakes. Still, some 7.3 million recreational boats fit this criterion (see Table 17).

The majority of recreational boats are used on inland waters or, when used in the ocean, within 3 nmi from shore. When operating in these waters, boaters are prohibited from disposing of any garbage overboard. Beyond 3 nmi from shore, limited dumping may occur.

In order to identify those boats prohibited from any overboard disposal, several assumptions were made. First, only boats registered in coastal states are assumed to operate in the ocean. Secondly, only larger boats are assumed to operate beyond 3 nmi from shore. Within coastal and Great Lakes states, the size breakdown of the registered boating fleet is as follows:

- 56.3% are under 4.9 m (16 ft) long,
- 39.6% are between 4.9 and 7.9 m (16 and 26 ft) in length, and
- 3.7% are greater than 7.9 m (26 ft) in length (see Table 17).

Table 16.--Estimates of annual quantities of plastic fishing gear wastes generated in the U.S. fisheries (Eastern Research Group estimates) (GT = gross tons, MT = metric tons).

Vessel category	Number of vessels	Annual quantities of fishing waste generated: Vessels generating normal quantities[a] (MT)	(m^3)	Vessels generating additional quantities[b] (MT)	(m^3)
Undocumented	105,500	1,779	131,781	0	0
Documented					
5-25 GT	14,815	216	12,570	23	1,323
25-300 GT	9,258	135	7,855	14	827
300-1,000 GT	188	3	160	0	0
Over 1,000 GT	40	1	34	0	0
Foreign vessels	NA	NA	NA	NA	NA
Total	129,801	2,133	152,400	37	2,150

[a]Vessels using trawls, set nets, or pots. Plastic waste in these fisheries is essentially gear-related.

[b]Vessels active in bait fisheries (i.e., longlining) or herring fisheries which generate additional quantities of plastic waste in the form of bait wrappings or salt bags.

According to the Boat Owner's Association of the U.S. (BOATUS), recreational boats under 4.9 m (16 ft) in length "are most likely confined to inland lakes, rivers, and bays," and of those over 4.9 m (16 ft), only 10% are estimated to venture beyond 3 nmi from shore (Schwartz 1987). Based on this, approximately 219,000 boats are estimated to operate in areas where some overboard disposal of garbage is permitted. The remaining 13.1 million operate in areas where no garbage disposal may occur.

Garbage Generation

Voyage lengths and onboard complements for recreational boats of various sizes are shown in Table 18, which derives the per voyage and annual garbage quantities generated.

Offshore Oil and Gas Operations

Offshore oil and gas operations such as exploratory drilling, development drilling, and oil and gas production from offshore platforms are also covered by MARPOL Annex V. The restrictions which apply to such operations are different from those applicable to commercial and recreational vessels. Under Annex V, ocean disposal of all types of garbage, with the exception of ground food wastes, is prohibited. For operations located within 12 nmi from shore, even the disposal of ground food wastes is prohibited.

Table 17.--Recreational boats in coastal and Great Lakes states (U.S. Coast Guard 1987a).

Region	Class and size					
	Class A <4.9 m (<16 ft)	Class 1 4.9-7.9 m (16-26 ft)	Class 2 7.9-12.2 m (26-40 ft)	Class 3 12.2-19.8 m (40-65 ft)	Class 4 >19.8 m (>65 ft)	Total
Coastal states						
Number	2,548,709	1,955,105	212,458	22,754	1,806	4,740,832
Percent of total	53.8	41.2	4.5	0.5	0.0	100.0
Great Lakes states						
Number	1,540,340	916,301	55,846	4,540	232	2,517,259
Percent of total	60.7	37.2	1.9	0.3	0.0	100.0
Coastal and Great Lakes						
Number	4,089,049	2,871,406	268,304	27,294	2,038	7,258,091
Percent of total	56.3	39.6	3.7	0.4	0.0	100.0

Table 18.--Derivation of per voyage, per vessel, and annual domestic garbage quantities generated: recreational boats (Eastern Research Group estimates) (GT = gross tons, MT = metric tons).

Recreational boats	Voyage length (days)	Crew size	Person days per voyage	Per capita generation rate (kg/day)	Domestic garbage generation per voyage[a] Total garbage (kg)	Total garbage (m^3)	Dry garbage (kg)	Dry garbage (m^3)	Plastic garbage (kg)	Plastic garbage (m^3)	Annual ship utilization rate[c] (%)	Voyages per year	Garbage per year per vessel (kg)	No. of vessels	No. of entrances	Total garbage per year[b] (MT)	Total garbage per year[b] (m^3)
Coastal states																	
Under 4.9 m	1	4	4	1.0	4	0	2	0	0	0	6	22	88	2,548,709	NA	223,267	1,455,671
4.9-7.9 m	1	4	4	1.0	4	0	2	0	0	0	6	22	88	1,955,105	NA	171,267	1,116,640
7.9-12.2 m	1	4	4	1.0	4	0	2	0	0	0	6	22	88	212,458	NA	18,611	121,343
12.2-19.8 m	1	4	4	1.0	4	0	2	0	0	0	6	22	88	22,754	NA	1,993	12,996
Over 19.8 m	2	6	12	1.5	18	0	11	0	1	0	6	11	197	1,806	NA	356	2,321
Subtotal																415,495	2,708,971
Great Lakes states																	
Under 4.9 m	1	4	4	1.0	4	0	2	0	0	0	6	22	88	1,540,340	NA	134,934	879,751
4.9-7.9 m	1	4	4	1.0	4	0	2	0	0	0	6	22	88	916,301	NA	80,268	523,337
7.9-12.2 m	1	4	4	1.0	4	0	2	0	0	0	6	22	88	56,105	NA	4,915	32,044
12.2-19.8 m	1	4	4	1.0	4	0	2	0	0	0	6	22	88	4,540	NA	398	2,593
Over 19.8 m	2	6	12	1.5	18	0	11	0	1	0	6	11	97	232	NA	46	298
Subtotal																220,560	1,438,022
Total garbage per year																636,055	4,146,994

[a]Dry garbage is calculated as 59.4% of total garbage by weight. Plastic garbage is 6.7% of dry garbage by weight. See Table 4.
[b]Total garbage weight per year is equal to the product of either (1) per vessel population, or (2) garbage quantity per voyage and the number of entrances.
[c]Refers to the percentage of days annually operating in U.S. waters.

Mobile Offshore Drilling Units

Data from the Department of the Interior's Minerals Management Service (MMS) for February 1988 showed there to be 124 mobile offshore drilling units (MODU's) active in U.S. Federal waters (L. M. Tracey, Department of the Interior, Minerals Management Services, pers. commun. 1988). All but one of these were reported to be operating beyond 12 nmi from shore. Approximately 78 MODU's were active in state waters (J. Dees, Ocean & Oil Weekly, Houston, TX, pers. commun. 1988). State waters extend out to 3 nmi from shore, except off Florida and Texas, where the state-federal boundary occurs at 3 leagues or approximately 10.35 nmi. All activity in state waters is subject to the complete ban on disposal within 12 nmi of shore, while MODU's in Federal waters would be able to dispose of ground food wastes. The MMS data indicate that MODU's in Federal waters have an average of 40 beds. This figure has been used as an estimate of the number of men aboard MODU's on a 24-h basis. Active MODU's are assumed to operate at 100% utilization.

Platforms

Approximately 3,500 production platform "complexes," consisting of one or more platforms in a single location, actively operate in U.S. Federal waters. Of these, however, only 779 are manned. A total of 124 manned platforms are situated within 12 nmi from shore, while the remaining 655 are located beyond 12 nmi. Dees (pers. commun. 1988) estimates that a maximum of 40 additional manned platforms are active in state waters.

The MMS data indicate that platform complexes have an average of 15 beds each.

Offshore Service Vessels

Service vessels employed in petroleum support activities are also covered by Annex V prohibitions. This category includes supply ships, tugs, anchor-handling vessels, crew ships, and research and survey vessels. Coast Guard data indicate that there are 484 offshore service vessels (OSV's) operating in the Federal Outer Continental Shelf region. Most crew and supply ships fall in the 50-200 dwt range. These are assumed to carry crews of five persons, and to make trips lasting an average of 1 day.

No data are available to indicate how many OSV's operate in state waters. Assuming the same ratio of structures (MODU's and platforms) to OSV's exists in state waters as in Federal waters, it is estimated that there are 63 additional OSV's active in state waters (484 + 903) x 118).

Garbage Generation

Garbage quantities for the offshore oil and gas sector are calculated in Table 19 on a per day, rather than a per voyage basis, since the structures are stationary and relatively permanent. Currently, all garbage with the exception of food wastes is required by the MMS to be transported to shore for disposal.

Table 19.--Derivation of per voyage, per vessel, and annual domestic garbage quantities generated: offshore oil and gas (Eastern Research Group estimates) (GT - gross tons, MT - metric tons).

Offshore oil and gas operations	Voyage length (days)	Crew size	Person days per voyage	Per capita generation rate (kg/day)	Domestic garbage generation per voyage[a]: Total garbage (kg)	Total garbage (m^3)	Dry garbage (kg)	Dry garbage (m^3)	Plastic garbage (kg)	Plastic garbage (m^3)	Annual ship utilization rate[c] (%)	Voyages per year	Garbage per year per vessel (kg)	No. of vessels	No. of entrances	Total garbage per year[b] (MT)	Total garbage per year[b] (m^3)
Mobile offshore drilling units																	
Within 12 nmi	1	40	40	2.0	80	1	48	0	5	0	100	365	29,200	74	NA	2,161	14,088
Outside 12 nmi	1	40	40	2.0	80	1	48	0	5	0	100	365	29,200	123	NA	3,592	23,417
Offshore oil and gas production platforms																	
Within 12 nmi	1	15	15	2.0	30	0	18	0	2	0	100	365	10,950	655	NA	7,172	46,762
Outside 12 nmi	1	15	15	2.0	30	0	18	0	2	0	100	365	10,950	655	NA	7,172	46,762
Offshore service vessels	1	5	5	2.0	10	0	6	0	1	0	100	365	3,650	545	NA	1,989	12,970
Total garbage per year																16,710	108,945

[a]Dry garbage is calculated as 59.4% of total garbage by weight. Plastic garbage is 6.7% of dry garbage by weight. See Table 4.

[b]Total garbage weight per year is equal to the product of either (1) per vessel population, or (2) garbage quantity per voyage and the number of entrances.

[c]Refers to the percentage of days annually operating in U.S. waters.

Research and Other Miscellaneous Vessels

Several categories of miscellaneous vessels have also been included in this analysis. These include vessels operated by universities and other oceanographic research institutions, maritime academy training ships, and various "industrial" vessels such as dredges and cable-laying ships.

Research Vessels

Numerous universities as well as private and nonprofit groups (e.g., Greenpeace, the Cousteau Foundation), operate oceanographic research vessels. The Coast Guard's MSIS data base indicates that in 1987 there were 26 vessels actively involved in oceanographic research (Coast Guard 1987b).

A 1978 profile of the world's oceanographic research fleet indicated that a typical research cruise might involve 20-25 crew members and 10-20 scientists (Trillo 1978; cited in Parker et al. 1987). These estimates were deemed appropriate by individuals connected with two major oceanographic research institutes, the Woods Hole Oceanographic Institute (J. Colburn, Woods Hole Oceanographic Institute, pers. commun. 1988) and the Scripps Institution of Oceanography (G. Schorr, Associate Director, Scripps Institution of Oceanography, La Jolla, CA, pers. commun. 1987).

School Training Vessels

Seven maritime academies in the United States operate a total of 14 ships used for training (Coast Guard 1987b). Seven of these are ocean-designated, six are authorized for coastwise travel, and one carries a Great Lakes designation. Only five of the vessels are greater than 1,000 GT in size.

Training ships of 1,000 GT or over are estimated to carry 150 men, while those under 1,000 GT are estimated to carry a crew of 50. Voyage lengths are estimated at 15 and 7 days, respectively. These estimates are based on discussions with officials at the Massachusetts Maritime Academy, who are familiar with the sizes and operations of vessels used at their and other maritime academies (D. Kan, Massachusetts Maritime Academy, Buzzard's Bay, MA, pers. commun. 1987).

Industrial Vessels

The category of industrial vessels comprises an assortment of vessel types including dredges, cable-laying ships, and drilling ships. Their common characteristic is that they carry crews who perform functions other than operating the vessel. The Coast Guard's MSIS data base indicates that in 1987 there were a total of 85 such vessels. Of these, 57 were greater than 1,000 GT, while 22 were under 1,000 GT. Furthermore, 69 were ocean-designated, while 17 were designated for coastal operation only.

While it is difficult to generalize about these vessels as a group, voyage lengths and crew complements on board have been approximated.

Oceangoing industrial vessels of 1,000 GT or over are estimated to carry an average of 30 persons on board and have voyage lengths averaging 15 days. Coastal vessels of 1,000 GT are also assumed to carry crews of 30 men, but are at sea for an average of 7 days. Both oceangoing and coastal vessels under 1,000 GT are estimated to carry 15 persons and to operate over 7-day voyages.

Garbage Generation

Domestic garbage.--Estimates of garbage generation in these sectors are shown in Table 20. School training ships and research vessels over 1,000 GT generate substantial quantities of garbage and plastics. Large research vessels, for example, may generate over 10 m^3 of plastics from domestic sources alone. This would be sufficient to fill an average commercial garbage dumpster.

Research vessel wastes.--The additional quantities of plastics associated with oceanographic research wastes are derived in Table 21.

U.S. Navy

Data from the Jane's Fighting Ships (1986) indicate that the U.S. Navy fleet currently numbers approximately 679 active vessels (see Table 22). Normal operational cycles for Navy vessels involve one 6-month tour of duty outside of U.S. waters every 18 months (D. Steigman, Jane's Publishing Co., pers. commun. 1988). Consequently, at any given time approximately one-third of the Navy fleet is operating outside of U.S. waters.

Crew complements on board Navy vessels range from 25 men up to as many as 5,000 on board the largest aircraft carriers. Where a range of crew sizes was reported, crew complements shown in Table 22 represent the average. Utilization factors while in U.S. waters range from 20 to 75%, depending on the vessel's strategic importance and its re-fit cycle (Mullenhard, pers. commun. 1988). Steigman (pers. commun. 1988) provided separate estimates of operating ratios for each class of Navy vessel, which are used to derive garbage quantity estimates for these ships while in U.S. waters.

Garbage Generation

Because of the large crew sizes and extended periods at sea, several categories of Navy ships are seen in Table 23 to generate extremely large quantities of wastes. Aircraft carriers with 5,000 men aboard, for example, could generate as much as 200 MT of garbage over a 20-day cruise. Several other categories of ships may generate 10 to 20 MT as well. Clearly, the Navy has particular garbage handling problems.

U.S. Coast Guard

The Coast Guard operates a large fleet of vessels, ranging from small harbor patrol boats to a pair of 121.9-m (400-ft) icebreakers. Table 24 provides a summary of the Coast Guard's fleet and indicates the number of

Table 20.--Derivation of per voyage, per vessel, and annual domestic garbage quantities generated: miscellaneous vessel categories (Eastern Research Group estimates) (GT = gross tons, MT = metric tons).

Miscellaneous vessels	Voyage length (days)	Crew size	Person days per voyage	Per capita generation rate (kg/day)	Domestic garbage generation per voyage[a]: Total garbage (kg)	Total garbage (m^3)	Dry garbage (kg)	Dry garbage (m^3)	Plastic garbage (kg)	Plastic garbage (m^3)	Annual ship utilization rate[c] (%)	Voyages per year	Garbage per year per vessel (kg)	No. of vessels	No. of entrances	Total garbage per year[b] (MT)	Total garbage per year[b] (m^3)
School training																	
1,000 GT and over	15	150	2,250	2.0	4,500	29	2,673	26	302	19	35	9	38,325	5	NA	192	1,249
Under 1,000 GT																	
Ocean	7	50	350	2.0	700	5	416	4	47	3	35	18	12,775	2	NA	26	167
Coastal	7	50	350	1.5	525	3	312	3	35	2	35	18	9,581	5	NA	48	312
Industrial vessels																	
1,000 GT and over																	
Ocean	15	30	450	2.0	900	6	535	5	60	4	75	18	16,425	52	NA	854	5,569
Coastal	7	30	210	1.5	315	2	187	2	21	1	75	39	12,319	11	NA	136	883
Under 1,000 GT																	
Ocean	7	15	105	2.0	210	1	125	1	14	1	75	39	8,213	17	NA	140	910
Coastal	7	15	105	1.5	158	1	94	1	11	1	75	39	6,159	5	NA	31	201
Research vessels																	
Inspected																	
1,000 GT and over	25	50	1,250	2.0	2,500	16	1,485	15	168	10	35	5	12,775	2	NA	26	167
300-1,000 GT	15	50	750	1.5	1,125	7	668	7	75	5	35	9	9,581	15	NA	144	937
Uninspected																	
Under 300 GT	10	25	250	1.5	375	2	223	2	25	2	35	13	4,791	9	NA	43	281
Total garbage per year																1,637	10,676

[a]Dry garbage is calculated as 59.4% of total garbage by weight. Plastic garbage is 6.7% of dry garbage by weight. See Table 4.
[b]Total garbage weight per year is equal to the product of either (1) per vessel population, or (2) garbage quantity per voyage and the number of entrances.
[c]Refers to the percentage of days annually operating in U.S. waters.

Table 21.--Estimates of annual quantities of additional plastic wastes generated by oceanographic research vessels (Eastern Research Group estimates) (GT = gross tons).

Vessel category	Number of vessels	Voyage length (days)	Voyages per year[a]	Additional waste per year (m^3)
Private vessels				
1,000 GT and over	2	25	5	1.17
300-1,000 GT	15	10	13	22.78
Under 300 GT	9	10	13	13.67
National Oceanic and Atmospheric Administration vessels				
Large deepwater vessels	4	25	5	2.34
Small coastal vessels	20	10	13	30.37
Total	50			70.32

[a]Annual vessel utilization of 35% is assumed.

vessels in each class, the crew complement, and typical voyage durations. This table is based upon discussions with Coast Guard operations personnel.

Coast Guard vessels are assumed to operate entirely within U.S. waters. Utilization factors for Coast Guard vessels are similar to those of Navy ships, and are assumed to average 50%.

Garbage Generation

Several categories of Coast Guard cutters as well as the large polar icebreakers are estimated to generate substantial quantities of garbage over representative voyages. The relevant quantities are shown in Table 25.

U.S. Army

The U.S. Army reports a fleet of approximately 580 crafts (G. Danish, U.S. Army, pers. commun. 1988). Of these, only a small number are "sea deployable." As shown in Table 26, these include four logistic support vessels approximately 91.4 m (300 ft) in length, 35 utility class landing craft capable of extended trips at sea, and 10 large oceangoing tugs.

The rest of the Army's fleet is made up of approximately 490 "ship-to-beach" craft of various types, used mainly for shuttling troops and supplies to and from larger vessels anchored offshore. In addition, the

Table 22.--U.S. Navy vessels by type and status (Jane's Fighting Ships 1986; Navy League of the United States 1987).

Vessel type	Active	Building/ reactivating conversion	Approximate onboard complement	[a]Estimated manpower total
Strategic missile submarines	38	5	150	5,700
Attack submarines	101	15	140	14,140
Aircraft carriers	13	3	5,000	65,000
Battleships	2	2	1,500	3,000
Cruisers	31	13	500	15,500
Destroyers	68	1	350	23,800
Frigates	100	4	300	30,000
Light forces	7	0	25	175
Light amphibious warfare ships	57	7	700-2,800	99,750
Mine warfare ships	3	6	70	210
Auxiliary ships	79	3	100-1,000	35,550
Military Sealift Command	72	18	25-120	5,220
Ready reserve force	73	0	40-1,200	45,260
Naval reserve	35	0	NA	NA
Total	679	77		343,305

[a]Where crew complements vary within a class, the arithmetic mean of the range is used. Total estimated complement is derived by dividing average complement by the number of active vessels.

Army maintains 15 small harbor tugs and about 25 small outboard motor-powered J boats.

These craft are used only intermittently during peacetime in logistics exercises. A utilization rate of 35% is assumed for all vessels.

Garbage Generation

The largest Army ships, the logistic support vessels, carrying 40 persons on board for up to 30 days, may generate close to 2 MT of garbage and 10 m^3 of plastics alone. Other vessel classes generate considerably smaller quantities of garbage.

National Oceanic and Atmospheric Administration Research Vessels

The NOAA operates a fleet of approximately two dozen vessels which are engaged in atmospheric and oceanographic research (B. Cunningham, Office of NOAA Corps, NOAA, pers. commun. 1988). These vessels range in size from 250 to 4,000 GT. Smaller vessels are estimated to carry approximately 10 persons on board, and to remain at sea for periods of approximately 1 week.

Table 23.--Derivation of per voyage, per vessel, and annual domestic garbage quantities generated: U.S. Navy vessels (Eastern Research Group estimates) (GT = gross tons, MT = metric tons).

U.S. Navy vessels	Voyage length (days)	Crew size	Person days per voyage	Per capita generation rate (kg/day)	Domestic garbage generation per voyage[a]: Total garbage (kg)	Total garbage (m^3)	Dry garbage (kg)	Dry garbage (m^3)	Plastic garbage (kg)	Plastic garbage (m^3)	Annual ship utili-zation rate[c] (%)	Voyages per year	Garbage per year per vessel (kg)	No. of vessels	No. of entrances	Total garbage per year[b] (MT)	Total garbage per year[b] (m^3)
Strategic missile submarines	3	150	450	2.0	900	6	535	5	60	4	3	3	2,973	38	NA	113	737
Attack submarines	7	140	980	2.0	1,960	13	1,164	12	131	8	6	3	6,624	101	NA	669	4,362
Aircraft carriers	20	5,000	100,000	2.0	200,000	1,304	118,800	1,177	13,400	837	22	4	811,111	13	NA	10,544	68,748
Battleships	20	1,500	30,000	2.0	60,000	391	35,640	353	4,020	251	33	4	243,333	2	NA	487	3,173
Cruisers	20	500	10,000	2.0	20,000	130	11,880	118	1,340	84	22	4	81,111	31	NA	2,514	16,394
Destroyers	20	350	7,000	2.0	14,000	91	8,316	82	938	59	22	4	56,778	68	NA	3,861	25,172
Frigates	20	300	6,000	2.0	12,000	78	7,128	71	804	50	22	4	48,667	100	NA	4,867	31,730
Light forces	15	25	375	2.0	750	5	446	4	50	3	22	5	4,056	7	NA	28	185
Light amphibious warfare ships	5	1,750	8,750	2.0	17,500	114	10,395	103	1,173	73	22	16	283,889	57	NA	16,182	105,502
Mine warfare ships	15	70	1,050	2.0	2,100	14	1,247	12	141	9	22	5	11,356	3	NA	34	222
Auxiliary ships	15	500	7,500	2.0	15,000	98	8,910	88	1,005	63	22	5	81,111	79	NA	6,408	41,778
Military Sealift Command	15	75	1,125	2.0	2,250	15	1,337	13	151	9	22	5	12,167	72	NA	876	5,711
Ready reserve force	15	620	9,300	2.0	18,600	121	11,048	109	1,246	78	33	8	150,867	73	NA	11,013	71,805
Naval reserve	15	620	9,300	2.0	18,600	121	11,048	109	1,246	78	0	0	0	35	NA	0	0
Total garbage per year																57,596	375,520

[a]Dry garbage is calculated as 59.4% of total garbage by weight. Plastic garbage is 6.7% of dry garbage by weight. See Table 4.
[b]Total garbage weight per year is equal to the product of either (1) per vessel population, or (2) garbage quantity per voyage and the number of entrances.
[c]Refers to the percentage of days annually operating in U.S. waters.

Table 24.--U.S. Coast Guard fleet by type and status (Jane's Fighting Ships 1986; Navy League of the United States 1987).

Vessel type	Active	Reserve	Under construction	Approximate complement
Cutters, high endurance	15	--	--	171
Cutters, medium endurance	34	--	7	82
Icebreakers	6	--	--	161
Icebreaking tugs	8	--	1	17
Surface effect craft	3	--	--	18
Large patrol craft	83	--	8	11
Training cutter	1	--	--	245
Buoy tenders, seagoing	28	--	--	53
Buoy tenders, coastal	12	--	--	20
Buoy tenders, inland	6	--	--	20
Buoy tenders, river	18	--	--	20
Construction tenders, inland	17	--	--	20
Harbor tugs, medium	4	--	--	10
Harbor tugs, small	14	--	--	10
Total	249	--	16	--

Larger vessels make voyages of up to 1 month and typically carry some 20 officers, 55 to 60 crewmen, and up to 30 scientists.

Approximately half of these vessels operate out of the NOAA base in Seattle, while the other half are stationed in Newport News. Other bases maintained by NOAA include Woods Hole, Miami, Pascagoula, and San Diego, as well as one each in Alaska and Hawaii.

Garbage Generation

The largest NOAA ships may generate as much as 4 MT of garbage over a typical 20-day voyage, and close to 20 m^3 of plastics from domestic sources alone, as shown in Table 27.

Wastes associated with the research activities of these ships are derived along with those of private research vessels in Table 21.

Other Government Vessels

Other Federal Government agencies such as the Customs Bureau and the U.S. Army Corps of Engineers, as well as numerous state and local government departments and agencies, may operate modest fleets of boats. No large craft, however, are estimated to be operated by agencies other than those discussed above. Smaller boats are included in the data presented in the section on recreational boats, but are not separately analyzed here.

Table 25.--Derivation of per voyage, per vessel, and annual domestic garbage quantities generated: U.S. Coast Guard vessels (Eastern Research Group estimates) (GT - gross tons, MT - metric tons).

U.S. Coast Guard vessels	Voyage length (days)	Crew size	Person days per voyage	Per capita generation rate (kg/day)	Domestic garbage generation per voyage[a]: Total garbage (kg)	Total garbage (m^3)	Dry garbage (kg)	Dry garbage (m^3)	Plastic garbage (kg)	Plastic garbage (m^3)	Annual ship utilization rate[c] (%)	Voyages per year	Garbage per year per vessel (kg)	No. of vessels	No. of entrances	Total garbage per year[b] (MT)	Total garbage per year[b] (m^3)
Icebreakers																	
Polar class 121.9 m	90	140	12,600	2.0	25,200	164	14,969	148	1,688	105	50	2	51,100	2	NA	102	666
Mackinaw class 73.2 m	6	75	450	2.0	900	6	535	5	60	4	50	30	27,375	1	NA	27	178
Bay class 42.7 m	6	17	102	2.0	204	1	121	1	14	1	50	30	6,205	9	NA	56	364
High endurance cutters																	
115.2 m	60	156	9,360	2.0	18,720	122	11,120	110	1,254	78	50	3	56,940	12	NA	683	4,455
82.3 m	60	109	6,540	2.0	13,080	85	7,770	77	875	55	50	3	39,785	10	NA	398	2,594
Medium endurance cutters																	
64.0 m	30	71	2,130	2.0	4,260	28	2,530	25	285	18	50	6	25,915	16	NA	415	2,703
61.9-64.9 m	30	75	2,250	2.0	4,500	29	2,673	26	302	19	50	6	27,375	10	NA	274	1,785
Patrol boats																	
33.5 m	10	16	160	2.0	320	2	190	2	21	1	50	18	5,840	23	NA	134	876
29.0 m	3	13	39	1.5	59	0	35	0	4	0	50	61	3,559	15	NA	53	348
25.0 m	2	10	20	1.5	30	0	18	0	2	0	50	91	2,738	15	NA	41	268
Buoy tenders																	
Seagoing	5	50	250	1.5	375	2	223	2	25	2	50	37	13,688	27	NA	370	2,409
Coastal	4	32	128	1.5	192	1	114	1	13	1	50	46	8,760	12	NA	105	685
River	5	18	90	1.0	90	1	53	1	6	0	50	37	3,285	18	NA	59	386
Inland	3	14	42	1.0	42	0	25	0	3	0	50	61	2,555	6	NA	15	100
Construction	5	8	40	1.0	40	0	24	0	3	0	50	37	1,460	16	NA	23	152
Harbor tugs																	
Medium	1	4	4	1.0	4	0	2	0	0	0	50	183	730	4	NA	3	19
Small	1	4	4	1.0	4	0	2	0	0	0	50	183	730	2,120	NA	1,548	10,090
Search and rescue <19.8 m	1	4	4	1.0	4	0	2	0	0	0	50	183	730	2,120	NA	1.548	10,090
Total garbage per year																4,317	28,146

[a]Dry garbage is calculated as 59.4% of total garbage by weight. Plastic garbage is 6.7% of dry garbage by weight. See Table 4.

[b]Total garbage weight per year is equal to the product of either (1) per vessel annual garbage quantity and the vessel population, or (2) garbage quantity per voyage and the number of entrances.

[c]Refers to the percentage of days annually operating in U.S. waters.

Table 26.--Derivation of per voyage, per vessel, and annual domestic garbage quantities generated: U.S. Army vessels (Eastern Research Group estimates) (GT - gross tons; MT - metric tons).

U.S. Army vessels	Voyage length (days)	Crew size	Person days per voyage	Per capita generation rate (kg/day)	Domestic garbage generation per voyage[a]: Total garbage (kg)	Total garbage (m^3)	Dry garbage (kg)	Dry garbage (m^3)	Plastic garbage (kg)	Plastic garbage (m^3)	Annual ship utilization rate[c] (%)	Voyages per year	Garbage per year per vessel (kg)	No. of vessels	No. of entrances	Total garbage per year[b] (MT)	Total garbage per year[b] (m^3)
Logistic support vessels	30	40	1,200	2.0	2,400	16	1,426	14	161	10	35	4	10,220	4	NA	41	267
Landing craft, utility class 2000	20	10	200	2.0	400	3	238	2	27	2	35	6	2,555	35	NA	89	583
Large oceangoing tugs	20	8	160	2.0	320	2	190	2	21	1	35	6	2,044	10	NA	20	133
Other small landing craft	2	5	10	1.0	10	0	6	0	1	0	35	64	639	491	NA	314	2,045
Small harbor tugs	2	5	10	1.0	10	0	6	0	1	0	35	64	639	15	NA	10	62
J-boats	2	5	10	1.0	10	0	6	0	1	0	35	64	639	25	NA	16	104
Total garbage per year																490	3,194

[a]Dry garbage is calculated as 59.4% of total garbage by weight. Plastic garbage is 6.7% of dry garbage by weight. See Table 4.
[b]Total garbage weight per year is equal to the product of either (1) per vessel annual garbage quantity and the vessel population, or (2) garbage quantity per voyage and the number of entrances.
[c]Refers to the percentage of days annually operating in U.S. waters.

Table 27.--Derivation of per voyage, per vessel, and annual domestic garbage quantities generated: National Oceanic and Atmospheric Administration (NOAA) research vessels (MT - metric tons, NA - not applicable). (Source: Eastern Research Group estimates.)

NOAA research vessels	Voyage length (days)	Crew size	Person days per voyage	Per capita generation rate (kg/day)	Domestic garbage generation per voyage[a]: Total garbage (kg)	Total garbage (m^3)	Dry garbage (kg)	Dry garbage (m^3)	Plastic garbage (kg)	Plastic garbage (m^3)	Annual ship utilization rate[c] (%)	Voyages per year	Garbage per year per vessel (kg)	No. of vessels	No. of entrances	Total garbage per year[b] (MT)	Total garbage per year[b] (m^3)
Large deepwater vessels	20	110	2,200	2.0	4,400	29	2,614	26	295	18	35%	6	28,105	10	NA	281	1,832
Coastal research vessels	5	10	50	2.0	100	1	59	1	7	0	35%	26	2,555	14	NA	36	233
Total garbage per year																317	2,066

[a]Dry garbage is calculated as 59.4% of total garbage by weight. Plastic garbage is 6.7% of dry garbage by weight. See Table 4.
[b]Total garbage weight per year is equal to the product of either (1) per vessel annual garbage quantity and the vessel population, or (2) garbage quantity per voyage and the number of entrances.
[c]Refers to the percentage of days annually operating in U.S. waters.

ACKNOWLEDGMENTS

The research contained in this paper is based upon work performed under contract for the Coast Guard and the U.S. Department of Transportation's Transportation Systems Center in Cambridge, Massachusetts. The authors wish to acknowledge the cooperation and support provided by these agencies.

REFERENCES

Berger, J. D., and C. E. Armistead.
1987. Discarded net material in Alaskan waters, 1982-84. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/NWC-110, 66 p.

Center for Environmental Education.
1986. Marine wildlife entanglement in North America. Center for Environmental Education, Wash., D.C., 219 p.

Corrado, E. J.
1986. Hearings before the Subcommittee on Oversight and Investigation of the Committee on Merchant Marine and Fisheries, House of Representatives. Letter from Ernest J. Corrado, Vice President, American Institute for Merchant Shipping to the Honorable Walter B. Jones, Chairman, Committee on Merchant Marine and Fisheries, U.S. House of Representatives, October 28, 1986.

Eastern Research Group.
1988a. Development of estimates of garbage disposal in the maritime sectors. Final report. Report prepared by the Eastern Research Group, Inc. for the Transportation Systems Center, Research and Special Programs Administration, U.S. Department of Transportation, December 1988, 139 p.

1988b. A regulatory evaluation of regulations implementing Annex V to MARPOL 73/78. Final report. Report prepared by the Eastern Research Group, Inc. for the Port Safety and Security Division, Program Development Branch, U.S. Coast Guard, December 1988, 333 p.

Gassan, M. C.
1978. Integrated waste disposal systems. Management Digest of Marine Research, Report No. E11.15TM.78 (October 1978). Marine Research Program, Exxon International Company, 22 p.

International Maritime Organization.
1987. Draft guidelines for the implementation of Annex V regulations for the prevention of pollution by garbage from ships. Marine Environmental Protection Committee, MEPC 26/10, 12 December 1987. International Maritime Organization: Lond.

Jane's Fighting Ships.
1986. Jane's fighting ships, 1986-87. Jane's Publishing Co.

Merrell, T. R. Jr.
1985. The fish nets and other plastic litter on Alaskan beaches. *In* R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii, p. 160-182. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54.

National Academy of Science.
1975. Marine litter. *In* Assessing potential ocean pollutants. A report of the study panel on assessing potential ocean pollutants to the Ocean Affairs Board, Commission on Natural Resources, National Research Council, p. 405-438. Natl. Acad. Sci., Wash., D.C.

National Solid Waste Management Association.
Undated. Solid waste disposal overview. National Solid Waste Management Association.

Naval Ship Engineering Center.
1971. Naval shipboard refuse study. Naval Ship Engineering Center, Hyattsville, MD, June 1971, 98 p.

Navy League of the United States.
1987. The almanac of seapower. Navy League of the United States, Arlington, VA.

Pacific Associates.
1988. A report to the Alaska Department of Environmental Conservation on the effects of MARPOL Annex V on the ports of Kodiak and Unalaska. Pacific Associates, September 1988, 64 p.

Parker, N. R., S. C. Hunter, and R. J. Yang.
1987. Development of methodology to reduce the disposal of non-degradable refuse into the marine environment. KVB, Inc., Engineering and Research Division, January 1987, 89 p.

Schwartz, R.
1987. Letter of 16 July 1987 from Richard Schwartz, President, Boat Owner's Association of the United States to Congressman Jerry Studds, Hearings before the Subcommittee on Coast Guard and Navigation and the Subcommittee on Fisheries and Wildlife Conservation and the Environment of the Committee on Merchant Marine and Fisheries, House of Representatives, 100th Congress, 17 June and 23 July 1987.

Society of Naval Architects and Marine Engineers.
1982. Guide for the disposal of shipboard wastes. Society of Naval Architects and Marine Engineers, Tech. Res. Bull. 3-33, January 1982.

Trillo, R. L. (editor).
1978. Jane's ocean technology. Franklin Watts, Inc., N.Y.

Uchida, R. N.
1985. The types and estimated amounts of fish net deployed in the North Pacific. *In* R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii, p. 37-108. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54.

U.S. Army Corps of Engineers.
1987. Summary of United States flag passenger and cargo vessels operating or available for operation on 1 November 1986. Unpublished table. U.S. Army Corps of Engineers, Waterborne Commerce Statistics Center.

U.S. Bureau of the Census.
1987. File AE-975, vessel entrances and clearances. Data base of monthly port entrances and clearances by vessels.

U.S. Coast Guard.
1987a. Boating statistics. Office of Boating Safety, Consumer and Public Affairs, 1987.

1987b. Unpublished statistical tables from the Marine Safety Inspection System data base. July 1987.

U.S. Maritime Administration.
1987a. Merchant marine data sheet. March 1, 1987, 7 p.

1987b. United States oceanborne foreign trade routes. U.S. Department of Transportation. December 1987.

[U.S.] National Marine Fisheries Service.
1987. Fisheries of the United States, 1986. Current Fishery Statistics 8385, 116 p.

APPENDIX

Detailed Garbage Generation Tables for 10 Maritime Sectors

(ERG estimates)

Appendix Table 1.--Final disposition of vessel-generated garbage before and after MARPOL Annex V (annual quantities) (GT = gross tons, MT = metric tons). Merchant shipping.

Merchant shipping	Total MT generated	Before MARPOL Annex V: Off-loaded in port		Before MARPOL Annex V: Incinerated at sea		Before MARPOL Annex V: Dumped overboard		After MARPOL Annex V[a]: Off-loaded in port: Plastics		After MARPOL Annex V[a]: Off-loaded in port: Other		After MARPOL Annex V[a]: Incinerated at sea		After MARPOL Annex V[a]: Dumped overboard	
		MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3
Foreign trade															
U.S. vessels															
Atlantic/Gulf/Pacific	1,124	0	0	56	733	1,067	13,919	46	1,459	0	0	323	4,212	754	3,523
Noncontiguous	42	0	0	2	27	40	519	2	54	0	0	12	157	28	131
Foreign vessels															
Atlantic/Gulf/Pacific	9,020	0	0	451	5,881	8,569	111,738	370	11,708	0	0	2,593	33,815	6,057	28,282
Noncontiguous/Great Lakes	833	0	0	42	543	791	10,319	34	1,081	0	0	239	3,123	559	2,612
Noncontiguous trade (U.S.)	1,166	0	0	58	760	1,108	14,446	55	1,705	0	0	224	2,927	886	4,139
Great Lakes vessels															
1,000 GT and over	397	298	970	99	1,294	0	0	7	3,014	93	147	99	1,294	198	927
Under 1,000 GT	48	36	117	12	156	0	0	1	364	11	18	12	156	24	112
Military Sealift charter (U.S.)	887	0	0	44	578	843	10,987	39	1,224	0	0	213	2,776	635	2,965
Temp. inactive vessels (U.S.)	115	0	0	6	75	109	1,424	5	159	0	0	28	360	82	384
Coastal shipping															
Ships															
1,000 GT and over	1,269	0	0	317	4,136	952	12,409	12	429	0	0	460	5,998	797	3,723
Under 1,000 GT	1,207	0	0	60	787	1,147	14,955	61	2,542	0	0	175	2,283	971	4,535
Tow/tugboats															
Large (inspected)	59	12	154	0	0	47	632	4	1,035	10	22	2	31	42	198
Small	14,783	2,957	38,552	0	0	11,826	157,955	990	286,579	2,623	6,068	0	0	11,169	52,154
Total	30,949	3,302	39,794	1,148	14,971	26,499	349,304	1,626	311,353	2,737	6,255	4,381	57,132	22,204	103,685

[a]Assumes full compliance with Annex V requirements.

Appendix Table 2.--Final disposition of vessel-generated garbage before and after MARPOL Annex V (annual quantities) (GT - gross tons, MT = metric tons). Commercial passenger ships.

Commercial passenger ships	Total MT generated	Before MARPOL Annex V: Off-loaded in port		Incinerated at sea		Dumped overboard		After MARPOL Annex V[a]: Off-loaded in port: Plastics		Other		Incinerated at sea		Dumped overboard	
		MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3
Cruise ships															
U.S. vessels															
>1,000 GT	1,577	1,577	20,561	0	0	0	0	106	13,191	1,471	6,870	0	0	0	0
Under 1,000 GT	3,784	3,595	46,879	0	0	189	2,467	254	31,025	3,531	16,157	0	0	0	0
Foreign vessels	7,978	5,744	74,899	638	8,322	1,596	20,805	5,733	267,957	0	0	1,117	14,564	1,128	5,265
Excursion vessels	188,270	178,856	2,332,241	0	0	9,413	122,750	12,614	1,543,483	175,656	803,829	0	0	0	0
Charter boats	56,465	42,349	552,219	0	0	14,116	184,073	3,783	448,745	52,682	233,701	0	0	0	0
Total	58,0742	232,121	3,026,799	638	8,322	25,315	330,095	22,490	2,304,400	233,340	1,060,557	1,117	14,564	1,128	5,265

[a]Assumes full compliance with Annex V requirements.

Appendix Table 3.--Final disposition of vessel-generated gargage before and after MARPOL Annex V (annual quantities) (GT = gross tons, MT = metric tons). Commercial fishing.

		Before MARPOL Annex V						After MARPOL Annex V[a]							
		Off-loaded in port		Incinerated at sea		Dumped overboard		Off-loaded in port				Incinerated at sea		Dumped overboard	
								Plastics		Other					
Commercial fishing	Total MT generated	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3
Undocumented	114,367	0	0	0	0	114,367	1,491,320	7,663	880,206	0	0	0	0	106,705	498,263
Documented															
5-25 GT	49,965	0	0	0	0	49,965	651,532	3,348	317,669	0	0	0	0	46,617	217,682
25-300 GT	66,908	0	0	0	0	66,908	872,457	4,259	151,124	0	0	3,345	43,623	59,304	276,921
300-1,000 GT	1,359	0	0	0	0	1,359	17,717	77	3,092	0	0	204	2,658	1,077	5,031
Over 1,000 GT	578	0	0	0	0	578	7,539	27	677	0	0	173	2,262	378	1,763
Foreign vessels[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total for sector	233,177	0	0	0	0	233,177	3,040,564	15,373	1,352,768	0	0	3,723	48,542	214,081	999,660

[a]Assumes full compliance with Annex V requirements.
[b]Data unavailable in time for this report. See Section 2.3 for discussion.

Appendix Table 4.--Final disposition of vessel-generated garbage before and after MARPOL Annex V (annual quantities) (MT = metric tons). Recreational boating.

Recreational boating	Total MT generated	Before MARPOL Annex V						After Annex V[a]							
		Off-loaded in port		Incinerated at sea		Dumped overboard		Off-loaded in port				Incinerated at sea		Dumped overboard	
								Plastics		Other					
		MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3
Coastal states															
Under 4.9 m	223,267	148,845	1,940,895	0	0	74,422	970,447	14,959	1,867,751	208,308	972,704	0	0	0	0
4.9-7.9 m	171,267	114,178	1,488,853	0	0	57,089	744,427	10,327	1,289,470	43,813	746,158	0	0	17,127	53,461
7.9-12.2 m	18,611	12,408	161,791	0	0	6,204	80,896	1,122	140,125	15,628	81,084	0	0	1,861	5,809
12.2-19.8 m	1,993	1,329	17,328	0	0	664	8,664	120	15,007	1,674	8,684	0	0	199	622
Over 19.8 m	356	237	3,094	0	0	119	1,547	19	2,219	269	1,509	0	0	68	211
Subtotal	415,495	276,996	3,611,961	0	0	138,498	1,805,981	26,548	3,314,573	369,692	1,810,140	0	0	19,255	60,103
Great Lakes states															
Under 4.9 m	134,934	89,956	1,173,001	0	0	44,978	586,500	8,137	1,015,916	113,304	587,865	0	0	13,493	42,119
4.9-7.9 m	80,268	53,512	697,782	0	0	26,756	348,891	4,840	604,337	67,401	349,703	0	0	8,027	25,055
7.9-12.2 m	4,915	3,277	42,725	0	0	1,638	21,363	296	37,004	4,127	21,412	0	0	491	1,534
12.2-19.8 m	398	265	3,457	0	0	133	1,729	24	2,994	334	1,733	0	0	40	124
Over 19.8 m	46	30	398	0	0	15	199	2	285	35	194	0	0	9	27
Subtotal	220,560	147,040	1,917,363	0	0	73,520	958,682	13,299	1,660,537	185,200	960,906	0	0	22,060	68,860
Total for sector	636,055	424,036	5,529,325	0	0	212,018	2,764,662	39,848	4,975,109	554,892	2,771,045	0	0	41,315	128,964

[a] Assumes full compliance with Annex V requirements.

Appendix Table 5.--Final disposition of vessel-generated garbage before and after MARPOL Annex V (annual quantities) (MT = metric tons). Offshore oil and gas operations.

Offshore oil and gas operations[b]	Total MT generated	Before MARPOL Annex V: Off-loaded in port MT	Before: Off-loaded in port m^3	Before: Incinerated at sea MT	Before: Incinerated at sea m^3	Before: Dumped overboard MT	Before: Dumped overboard m^3	After MARPOL Annex V[a]: Off-loaded in port, Plastics MT	After: Plastics m^3	After: Off-loaded in port, Other MT	After: Other m^3	After: Incinerated at sea MT	After: Incinerated at sea m^3	After: Dumped overboard MT	After: Dumped overboard m^3
Mobile offshore drilling units (MODU's)															
- within 12 nmi	2,161	1,284	16,737	0	0	877	2,738	145	18,076	2,016	9,414	0	0	0	0
- outside 12 nmi	3,592	2,133	27,819	0	0	1,458	4,552	0	0	0	15,647	0	0	0	0
Offshore oil and gas production platforms															
- within 12 nmi	1,796	1,067	13,910	0	0	729	2,276	120	15,023	1,675	7,824	0	0	0	0
- outside 12 nmi	7,172	4,260	55,553	0	0	2,912	9,090	0	0	0	31,247	0	0	0	0
Offshore service vessels (OSV's)	1,989	1,989	25,939	0	0	0	0	133	16,641	1,856	8,667	0	0	0	0
Total for sector	16,710	10,733	139,958	0	0	5,977	18,656	398	49,740	5,547	72,799	0	0	0	0

[a]Assumes full compliance with Annex V requirements.

[b]The MODU's, platforms, and OSV's are assumed to currently off-load all dry garbage in accordance with MMS and EPA requirements, hence only food wastes are shown as being dumped.

Appendix Table 6.--Final disposition of vessel-generated garbage before and after MARPOL Annex V (annual quantities) (GT = gross tons, MT = metric tons). Miscellaneous vessels.

Miscellaneous vessels	Total MT generated	Before MARPOL Annex V: Off-loaded in port MT	Before MARPOL Annex V: Off-loaded in port m^3	Before MARPOL Annex V: Incinerated at sea MT	Before MARPOL Annex V: Incinerated at sea m^3	Before MARPOL Annex V: Dumped overboard MT	Before MARPOL Annex V: Dumped overboard m^3	After MARPOL Annex V[a]: Off-loaded in port, Plastics MT	After MARPOL Annex V[a]: Off-loaded in port, Plastics m^3	After MARPOL Annex V[a]: Off-loaded in port, Other MT	After MARPOL Annex V[a]: Off-loaded in port, Other m^3	After MARPOL Annex V[a]: Incinerated at sea MT	After MARPOL Annex V[a]: Incinerated at sea m^3	After MARPOL Annex V[a]: Dumped overboard MT	After MARPOL Annex V[a]: Dumped overboard m^3
School training															
1,000 GT and over	192	0	0	0	0	192	2,499	9	224	0	0	57	750	125	584
Under 1,000 GT															
Ocean	26	0	0	0	0	26	333	1	51	0	0	5	67	19	89
Coastal	48	0	0	0	0	48	625	3	96	0	0	10	125	36	167
Industrial vessels															
1,000 GT and over															
Ocean	854	3	37	0	0	851	10,780	60	3,255	0	0	128	1,665	667	3,112
Coastal	136	0	6	0	0	135	1,710	10	516	0	0	20	264	106	494
Under 1,000 GT															
Ocean	140	0	6	0	0	139	1,762	10	625	0	0	14	181	116	541
Coastal	31	0	1	0	0	31	389	2	138	0	0	3	40	26	119
Research vessels															
Inspected															
1,000 GT and over	26	0	1	0	0	25	322	2	45	0	0	13	166	11	51
300-1,000 GT	144	0	6	0	0	143	1,814	10	324	0	0	43	560	91	423
Uninspected															
Under 300 GT	43	0	2	0	0	43	544	3	97	0	0	13	168	27	127
Total for sector	1,637	5	60	0	0	1,633	20,778	109	5,372	0	0	306	3,986	1,223	5,709

[a]Assumes full compliance with Annex V requirements.

Appendix Table 7.--Final disposition of vessel-generated garbage before and after MARPOL Annex V (annual quantities) (MT = metric tons). U.S. Navy.

U.S. Navy vessels	Total MT generated	Before MARPOL Annex V						After MARPOL Annex V[a]							
		Off-loaded in port		Incinerated at sea		Dumped overboard		Off-loaded in port: Plastics		Off-loaded in port: Other		Incinerated at sea		Dumped overboard	
		MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3
Strategic missile submarines	113	0	0	0	0	113	1,473	8	4,725	0	0	0	0	105	492
Attack submarines	669	0	0	0	0	669	8,724	45	27,984	0	0	0	0	624	2,915
Aircraft carriers	10,544	0	0	0	0	10,544	137,497	706	441,051	0	0	0	0	9,838	45,939
Battleships	487	0	0	0	0	487	6,346	33	20,356	0	0	0	0	454	2,120
Cruisers	2,514	0	0	0	0	2,514	32,788	168	105,174	0	0	0	0	2,346	10,955
Destroyers	3,861	0	0	0	0	3,861	50,345	259	161,492	0	0	0	0	3,602	16,821
Frigates	4,867	0	0	0	0	4,867	63,460	326	203,562	0	0	0	0	4,541	21,203
Light forces	28	0	0	0	0	28	370	2	1,187	0	0	0	0	26	124
Light amphibious warfare ships	16,182	0	0	0	0	16,182	211,005	1,084	676,843	0	0	0	0	15,097	70,498
Mine warfare ships	34	0	0	0	0	34	444	2	1,425	0	0	0	0	32	148
Auxiliary ships	6,408	0	0	0	0	6,408	83,556	429	268,023	0	0	0	0	5,978	27,917
Military Sealift Command	876	0	0	0	0	876	11,423	59	36,641	0	0	0	0	817	3,816
Ready reserve force	11,013	0	0	0	0	11,013	143,610	738	460,660	0	0	0	0	10,275	47,981
Naval reserve	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	57,596	0	0	0	0	57,596	751,040	3,859	2,409,124	0	0	0	0	53,737	250,929

[a]Assumes full compliance with Annex V requirements.

Appendix Table 8.--Final disposition of vessel-generated garbage before and after MARPOL Annex V (annual quantities) (MT = metric tons). U.S. Coast Guard.

U.S. Coast Guard vessels	Total MT generated	Before MARPOL Annex V: Off-loaded in port		Before MARPOL Annex V: Incinerated at sea		Before MARPOL Annex V: Dumped overboard		After MARPOL Annex V[a]: Off-loaded in port: Plastics		After MARPOL Annex V[a]: Off-loaded in port: Other		After MARPOL Annex V[a]: Incinerated at sea		After MARPOL Annex V[a]: Dumped overboard	
		MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3
Icebreakers															
Polar class 400 ft	102	0	0	0	0	102	319	7	4,275	0	0	0	0	95	298
Mackinaw class 240 ft	27	16	322	0	0	11	35	2	1,145	9	29	0	0	17	53
Bay class 140 ft	56	33	657	0	0	23	71	4	467	17	59	0	0	35	108
High endurance cutters															
378 ft	683	0	0	0	0	683	2,133	46	28,580	0	0	0	0	638	1,990
270 ft	398	0	0	0	0	398	1,242	27	16,641	0	0	0	0	371	1,159
Medium endurance cutters															
210 ft	415	0	0	0	0	415	1,294	28	17,343	0	0	0	0	387	1,208
203-213 ft	274	0	0	0	0	274	855	18	11,450	0	0	0	0	255	797
Patrol boats															
110 ft	134	80	1,581	0	0	55	170	9	5,618	42	143	0	0	83	260
95 ft	53	32	628	0	0	22	68	4	2,233	17	57	0	0	33	103
82 ft	41	24	483	0	0	17	52	3	1,718	13	44	0	0	25	79
Buoy tenders															
Seagoing	370	220	4,351	0	0	150	468	25	15,458	116	394	0	0	229	715
Coastal	105	62	1,238	0	0	43	133	7	4,397	33	112	0	0	65	203
River	59	35	696	0	0	24	75	4	2,473	19	63	0	0	37	114
Inland	15	9	180	0	0	6	19	1	641	5	16	0	0	10	30
Construction	23	14	275	0	0	9	30	2	977	7	25	0	0	14	45
Harbor tugs															
Medium	3	2	34	0	0	1	4	0	122	1	3	0	0	2	6
Small	10	6	120	0	0	4	13	1	427	3	11	0	0	6	20
Search and rescue boats <65 ft	1,548	919	18,219	0	0	628	1,961	104	12,947	484	1,648	0	0	959	2,995
Total	4,317	1,452	28,786	0	0	2,864	8,941	289	126,913	765	2,604	0	0	3,262	10,183

[a]Assumes full compliance with Annex V requirements.

Appendix Table 9.--Final disposition of vessel-generated garbage before and after MARPOL Annex V (annual quantities) (MT = metric tons). U.S. Army.

U.S. Army vessels	Total MT generated	Before MARPOL Annex V						After MARPOL Annex V[a]							
		Off-loaded in port		Incinerated at sea		Dumped overboard		Off-loaded in port: Plastics		Off-loaded in port: Other		Incinerated at sea		Dumped overboard	
		MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3
Logistic support vessels	41	0	0	0	0	41	533	3	1,710	0	0	0	0	17	52
Landing craft, utility class 2	89	0	0	0	0	89	1,166	6	3,740	0	0	0	0	36	113
Large oceangoing tugs	20	0	0	0	0	20	267	1	855	0	0	0	0	8	26
Other landing craft	314	0	0	0	0	314	4,090	21	2,624	0	0	0	0	127	397
Small harbor tugs	10	0	0	0	0	10	125	1	80	0	0	0	0	4	12
J-boats	16	0	0	0	0	16	208	1	134	0	0	0	0	6	20
Total	490	0	0	0	0	490	6,388	33	9,143	0	0	0	0	199	621

[a]Assumes full compliance with Annex V requirements.

Appendix Table 10.--Final disposition of vessel-generated garbage before and after MARPOL Annex V (annual quantities) (MT = metric tons). National Oceanic and Atmospheric Administration (NOAA) research vessels.

NOAA research vessels	Total MT generated	Before MARPOL Annex V						After MARPOL Annex V[a]							
		Off-loaded in port		Incinerated at sea		Dumped overboard		Off-loaded in port				Incinerated at sea		Dumped overboard	
								Plastics		Other					
		MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3
Large deepwater vessels	281	6	141	84	1,099	191	2,144	9	235	0	0	141	1,832	131	612
Coastal research vessels	36	1	24	4	47	31	319	2	96	0	0	7	93	27	125
Total	317	7	165	88	1,146	222	2,463	11	331	0	0	148	1,926	158	737

[a]Assumes full compliance with Annex V requirements.

Appendix Table 11.--Final disposition of vessel-generated garbage before and after MARPOL Annex V (annual quantities) (MT = metric tons). Summary table.

Sector	Total MT generated	Before MARPOL Annex V						After MARPOL Annex V[a]							
		Off-loaded in port		Incinerated at sea		Dumped overboard		Off-loaded in port: Plastics		Off-loaded in port: Other		Incinerated at sea		Dumped overboard	
		MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3
Merchant shipping	30,949	3,302	39,794	1,148	14,971	26,499	349,304	1,626	311,353	2,737	6,255	4,381	57,132	22,204	103,685
Commercial passenger ships	258,074	232,121	3,026,799	638	8,322	25,315	330,095	22,490	2,304,400	233,340	1,060,557	1,117	14,564	1,128	5,265
Commercial fishing	233,177	0	0	0	0	233,177	3,040,564	15,373	1,352,768	0	0	3,723	48,542	214,081	999,660
Recreational boating	636,055	424,036	5,529,325	0	0	212,018	2,764,662	39,848	4,975,109	554,892	2,771,045	0	0	41,315	128,964
Offshore oil and gas operations	16,710	10,733	139,958	0	0	5,977	18,656	398	49,740	5,547	72,799	0	0	0	0
Miscellaneous vessels	1,637	5	60	0	0	1,633	20,778	109	5,372	0	0	306	3,986	1,223	5,709
U.S. Navy	57,596	0	0	0	0	57,596	751,040	3,859	2,409,124	0	0	0	0	53,737	250,929
U.S. Coast Guard	4,317	1,452	28,786	0	0	2,864	8,941	289	126,913	765	2,604	0	0	3,262	10,183
U.S. Army	490	0	0	0	0	490	6,388	33	9,143	0	0	0	0	199	621
National Oceanic and Atmospheric Administration research vessels	317	7	165	88	1,146	222	2,463	11	331	0	0	148	1,926	158	737
Total	1,239,322	671,656	8,764,887	1,874	24,439	565,791	7,292,892	84,037	11,544,253	797,282	3,913,261	9,674	126,150	337,306	1,505,752

[a]Assumes full compliance with Annex V requirements.

THE QUANTITATIVE DISTRIBUTION AND CHARACTERISTICS OF MARINE DEBRIS IN THE NORTH PACIFIC OCEAN, 1984-88

Robert H. Day,* David G. Shaw
Institute of Marine Sciences
University of Alaska
Fairbanks, Alaska 99775, U.S.A.

and

Steven E. Ignell
Alaska Fisheries Science Center Auke Bay Laboratory
National Marine Fisheries Service, NOAA
Auke Bay, Alaska 99821, U.S.A.

*Present address Alaska Biological Research, P.O. Box 81934, College, Alaska 99708, U.S.A.

ABSTRACT

The distribution, abundance, and characteristics of marine debris in the North Pacific, Bering Sea, and Japan Sea were studied during the 5-year period 1984-88 using standardized observations at 181 daily transect stations encompassing approximately 21,420 km of observations, for a total of 1,070 km^2 of sampling. The most abundant debris type was plastic, which composed 89.3% of the total 2,127 debris items seen on transect; other debris items consisted of glass (3.3%), wood (3.2%), paper/fiber (2.4%), metal (0.5%), rubber (0.2%), and unidentified debris objects (1.0%). The most abundant plastic type was fragments (34.2%); other main plastic types were Styrofoam objects (22.5%), sheets and bags (18.2%), gillnet floats (5.0%), polypropylene line (3.1%), miscellaneous floats (2.8%), and miscellaneous/unidentified plastic objects (12.3%). Gillnet fragments, trawl net fragments, unidentified net fragments, and uncut plastic strapping, which were minor components of the plastic debris, were recorded a total of 46 times, primarily between lat. 37° and 44°N, in and near the Subarctic Front. The distribution and characteristics of the 6 general debris types are presented, as well as the distribution and characteristics of the 11 main plastic types. The highest densities of marine debris generally occurred in Japan Sea and nearshore Japan Water, Transitional Water, and Subtropical Water. Densities of most types of marine debris generally were low in Subarctic Water and Bering Sea Water. Heterogeneous geographic input, currents, and winds are important in locally concentrating marine debris.

In R. S. Shomura and M. L. Godfrey (editors), Proceedings of the Second International Conference on Marine Debris, 2-7 April 1989, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-154. 1990.

INTRODUCTION

Marine debris, especially plastic debris, increasingly is recognized as a national and international pollution problem (Shomura and Yoshida 1985; Wolfe 1987). Debris presents problems on beaches, where it is aesthetically displeasing, is expensive (and probably impossible) to remove, causes unnecessary mortality of coastal wildlife, and (in the case of some medical, military, and industrial wastes) is potentially toxic. Debris also can cause problems at sea, where it can damage vessels, entangle marine animals, and result in the deaths of some animals that mistake it for food. Although the general nature of the marine debris problem is understood, the actual magnitude of the problem is unknown, because much of the information about it is anecdotal. For instance, we know that the northern fur seal, *Callorhinus ursinus*, become entangled and die in derelict fishing nets at sea, but estimates of the abundance of derelict nets at sea are highly uncertain (Pruter 1987). Consequently, estimates of both the true mortality rate of fur seals due to entanglement and the true effects of this mortality on fur seal populations also are uncertain (but see Fowler 1982, 1985, 1987).

During the last two decades, several workers have systematically observed floating debris and lost plastic nets in the North Pacific Ocean (Venrick et al. 1973; DeGange and Newby 1980; Dahlberg and Day 1985; Jones and Ferrero 1985; Yoshida and Baba 1985; Baba et al. 1986; Day and Shaw 1987; Mio and Takehama 1987; Yagi and Nomura 1987) and stranded debris on coastal beaches (Merrell 1980, 1984). These studies have shown that marine debris is distributed widely, is of several types, and is distributed by surface currents and winds.

The objective of this study was to improve our knowledge of the quantitative distribution and characteristics of marine debris in the North Pacific Ocean. Specifically, we wanted to: (1) describe the quantitative distributions of the six main types of marine debris; (2) describe the comparative at-sea densities of the main debris types; (3) describe the mean dimensions of the main debris types; (4) describe the quantitative distributions of the 11 main types of plastic debris; (5) describe the frequencies of colors of the main plastic types; and (6) examine the effects of input, currents, and winds on the quantitative distribution of marine debris. Because of the extensive geographic coverage of the work, this study constitutes the first complete analysis and the most detailed synoptic picture of marine debris anywhere in the world ocean.

METHODS

We collected data on the density (number per square kilometer), types, sizes, and colors of marine debris at 181 debris transect stations in the Bering and Japan Seas and the North Pacific Ocean north of Hawaii. At each station, we counted, identified, and estimated the two largest dimensions (at least 2.5 × 2.5 cm) of marine debris within 50 m of one side of a ship moving forward at a known rate of speed for a known period of time (Dahlberg and Day 1985; Day and Shaw 1987). The only types of debris that were sampled as far as we could see from either side of a moving ship were gillnet fragments, trawl net fragments, unidentified net fragments, and uncut pieces of plastic strapping. This paper includes some published data from 38 stations in 1984 (Dahlberg and Day 1985) and 49 stations in 1985 (Day and Shaw 1987); the data from the other 94 stations are from 1986 to 1988 and have been combined with the 1984-85 data for a broader overview of patterns in the North Pacific.

The sampling surveyed approximately 21,425 km of ocean, for a total of approximately 1,073 km² of sampling (Fig. 1). The total effort consisted of 854 h 47 min (854:47) of sampling at 152 of the stations during which observation conditions were recorded. Effort by observation condition was: poor 21:50 (2.6% of the total effort of known conditions); fair 163:30 (19.1%); moderate 253:00 (29.6%); good 320:17 (37.5%); and very good 96:10 (11.3%). We decreased sampling effort when conditions were less than moderate (21.7% of total effort during known conditions) and sampled extensively when conditions were moderate to very good (78% of total effort during known conditions). Sampling was not conducted during periods when high waves could affect sightability of debris.

General debris types were standardized and consisted of glass, metal, paper/fiber, plastic, rubber, wood, or miscellaneous/unidentified debris. Plastic debris types also were standardized: fragment, Styrofoam (which may include foamed plastics of other chemical composition), polypropylene line fragment (which may include synthetic lines of other chemical composition), gillnet float, miscellaneous float, gillnet fragment, trawl net fragment, unidentified net fragment, uncut plastic strapping, sheet/bag, and miscellaneous/unidentified plastic debris. The two largest dimensions of pieces of debris were estimated in centimeters. Pieces of plastic debris were identified to the same standardized colors that were used for neuston plastic (Day et al. 1990): black/gray, blue, brown, green, orange, red/pink, tan, transparent, white, yellow, and mixed/unidentified colors.

Data were compiled as the density (number/km²) of total marine debris, of each general type of marine debris, and of each type of plastic debris at each station. We stratified the density data into five oceanographic water mass strata: Bering Sea Water, Subarctic Water (north of the Subarctic Front or north of approximately lat. 42°N), Subtropical Water (south of the Subtropical Front or south of approximately lat. 31°N), Japan Sea/nearshore Japan Water (west of approximately long. 150°E), and Transitional Water (Subarctic Front, Transition Zone, and Subtropical Front). We then subjected the stratified density data (total density, the 6 general debris types, and the 11 plastic debris types) to Kruskal-Wallis tests (Conover 1980; Zar 1984). For each data set, we tested the hypothesis:

H_0: The density does not vary among water masses.

When test results were significant, we conducted multiple comparison tests (Conover 1980) to determine which water masses were significantly different.

The size data were combined into 10-cm size classes for sizes up to 100 cm; larger debris items were combined into size classes 101-200 cm,

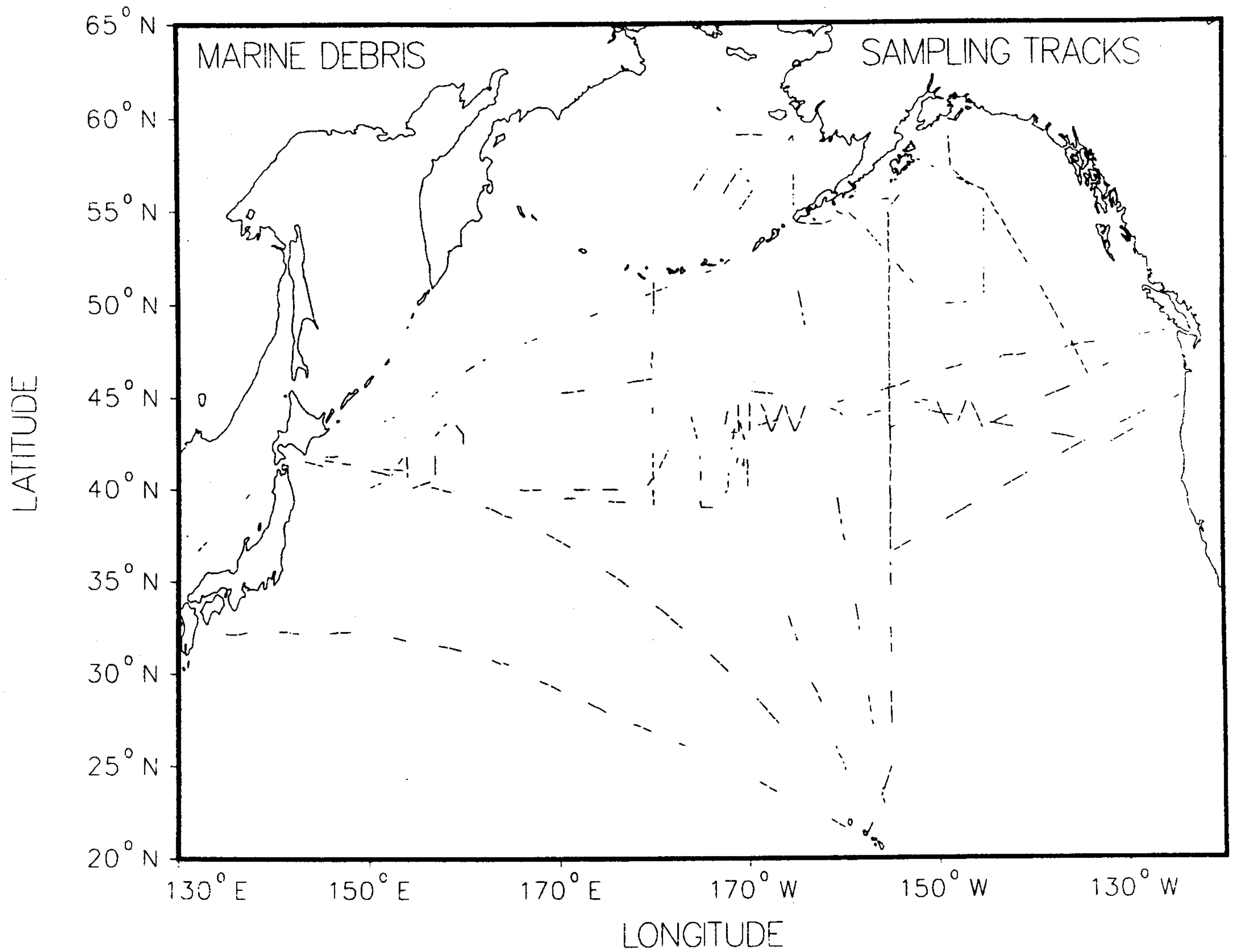


Figure 1.--Cruise tracks for marine debris sampling, 1984-88.

>200 cm, or unknown. The size data were compiled for each of the six general debris types but not for the individual plastic types. The color data were compiled as frequencies of each color of plastic; subsequently, these frequencies were divided by the total number of plastic items to determine percentages of each color type.

RESULTS

Total Debris

We recorded 2,127 debris objects on the 181 debris transects. Plastic was the most common general type of debris, being recorded 1,899 times (89.3% of the total number of debris objects). Glass was next in frequency (72 objects; 3.3%), followed by 68 wood objects (3.2%), 53 paper/fiber objects (2.4%), 10 metal objects (0.5%), and 4 rubber objects (0.2%). Miscellaneous/unidentified marine debris was recorded 22 times (1.0%).

Marine debris was widespread in occurrence, but occurred in greatest densities in the Japan Sea and off the eastern coast of Japan; it also was common along the Subarctic Front and in southern Transitional Water (Fig. 2). Lowest densities were in the central Alaska Gyre, in the Bering Sea, and in the vicinity of the Hawaiian Islands. The highest density of total marine debris was 36.7 pieces/km^2 at lat. 36°55'N, long. 132°30'E in the Japan Sea. Densities of total marine debris differed significantly among water masses ($H = 66.735$; $n = 181$; $df = 4$; $P < 0.05$; Table 1). Multiple comparisons indicated that densities were: Japan Sea/nearshore Japan Water = Transitional Water = Subtropical Water > Subarctic Water = Bering Sea Water.

Glass Debris

Glass objects were recorded 72 times. Glass containers of various types (miscellaneous bottle, sake bottle, jar, beer bottle, and Japanese whisky bottle, in decreasing order of frequency) were recorded 54 times (75.0% of total glass); bottles were the most abundant, being recorded 42 times (58%). The second main class of glass objects was light bulbs (11 objects; 15.3%), which were represented (in decreasing order) by incandescent bulbs, fluorescent bulbs, and floodlights. The remaining seven (9.7%) glass objects consisted of glass fishing floats (glass balls). The mean dimensions of glass debris were 17.9 × 33.7 cm ($n = 34$ objects of known dimensions).

Glass debris was widespread south of the Subarctic Water, occurring in greatest densities in southern Transitional Water, in the Japan Sea, and off eastern Japan; it was uncommon in Subarctic Water and absent in the Bering Sea (Fig. 3). The highest density was 1.3 pieces/km^2 at lat. 30°34'N, long. 173°10'W in Subtropical Water northwest of the Hawaiian Islands. Densities of glass differed significantly among water masses ($H = 34.744$; $n = 181$; $df = 4$; $P < 0.05$; Table 1). Multiple comparisons tests were confusing, however, in that those water masses with the largest difference in mean ranks were not significantly different, whereas water masses with smaller differences in mean ranks were significantly different. The two water masses that were significantly different were Transitional Water > Subarctic Water, the two with the largest sample sizes (49 and 99, respectively). We suspect that other water masses were different but that sample sizes in most were too small for the multiple comparisons test to find significant differences. The pattern of mean ranks (in descending order) was: Japan Sea/nearshore Japan Water, Subtropical Water, Transitional Water, Subarctic Water, and Bering Sea Water.

Metal Debris

Metal objects were recorded 10 times. Metal cans of various sizes were the most common metal debris, being recorded eight times (80% of total metal). The remaining two metal objects were a 208.2 L (55-gal) drum and a metal trawl float (10% each). The mean dimensions of metal debris were 41.5 × 64.5 cm ($n = 5$ objects of known dimensions).

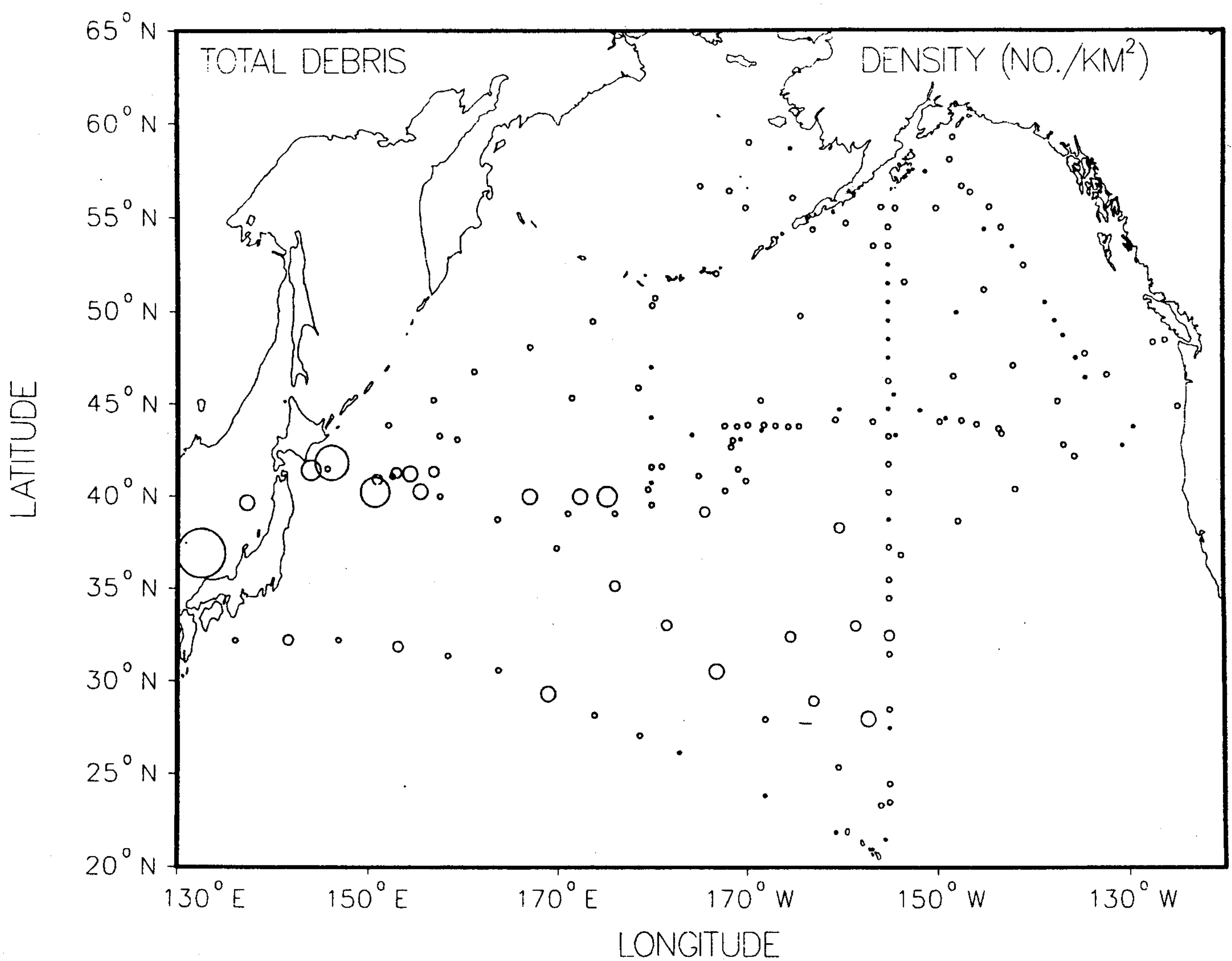


Figure 2.--Densities of total marine debris, 1984-88. Solid black circles indicate stations at which debris was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 36.7 pieces/km^2.

Metal debris was sporadic in occurrence and almost certainly originated from ships. The main areas of occurrence were the Japan Sea and off eastern Japan, with other records in the northern Gulf of Alaska and the eastern subarctic Pacific (Fig. 4). The highest density was 0.5 piece/km^2 at lat. 36°55'N, long. 132°30'E in the Japan Sea. Densities of metal debris appeared to differ significantly among water masses ($H = 10.106$; $n = 181$; $df = 4$; $P < 0.05$; Table 1). Multiple comparisons, however, indicated that none of the water masses were significantly different; we suspect that densities were too low overall for the multiple comparisons to find significant differences. The pattern of mean ranks (in descending order) was: Japan Sea/nearshore Japan Water, Transitional Water, Subarctic Water, and none in Subtropical and Bering Sea Waters.

Table 1.--Densities (number/km^2) of general types of marine debris in five water masses of the North Pacific, 1984-88.

Parameter	Bering Sea Water		Subarctic Water		Transitional Water		Subtropical Water		Japan Sea and nearshore Japan Water	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
n	7		99		49		18		8	
Distance sampled (km)	872.6		11,010.5		6,072.0		2,408.0		1,061.9	
Area sampled (km^2)	43.7		551.7		303.6		120.4		53.1	
Total density	0.3	0.3	0.4	0.6	3.6	3.8	2.4	3.5	11.5	12.8
Glass	0.0	0.0	<0.1	0.1	0.1	0.2	0.2	0.3	0.2	0.2
Metal	0.0	0.0	<0.1	<0.1	<0.1	<0.1	0.0	0.0	0.1	0.2
Paper/fiber	<0.1	0.1	<0.1	0.1	0.1	0.2	<0.1	0.1	0.1	0.8
Plastic	0.2	0.2	0.3	0.4	3.3	3.7	2.1	3.1	10.5	11.7
Rubber	0.0	0.0	0.0	0.0	<0.1	<0.1	0.0	0.0	0.1	0.1
Wood	<0.1	<0.1	0.1	0.3	<0.1	0.1	<0.1	0.1	0.2	0.2
Miscellaneous/ unidentified	<0.1	0.1	<0.1	<0.1	0.1	0.1	<0.1	0.1	0.0	0.0

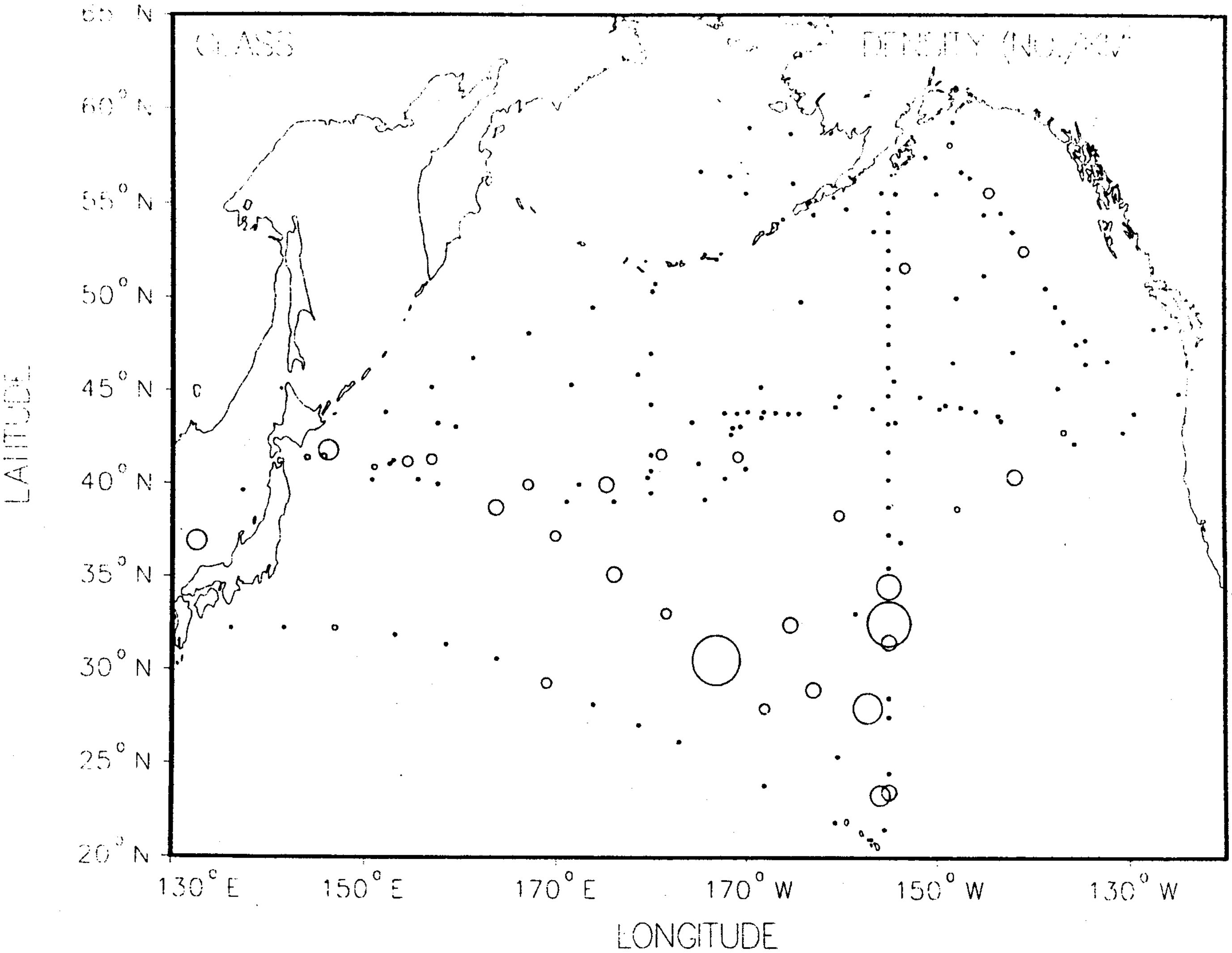


Figure 3.--Densities of glass debris, 1984-88. Solid black circles indicate stations at which glass debris was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 1.3 pieces/km².

Paper/Fiber Debris

Paper/fiber objects were recorded 53 times. Paperlike objects were the most common, being recorded 34 times (66.0% of total paper/fiber); of these, cardboard (fragments, boxes, sheets, and tubes) was recorded 19 times (35.8%), and paper (fragments, towels, cups, magazines, and cigarette packs) was recorded 16 times (30.2%). Hemp line was recorded 11 times (20.8%); it consisted of fragments of hemp deck lines from ships and of 1

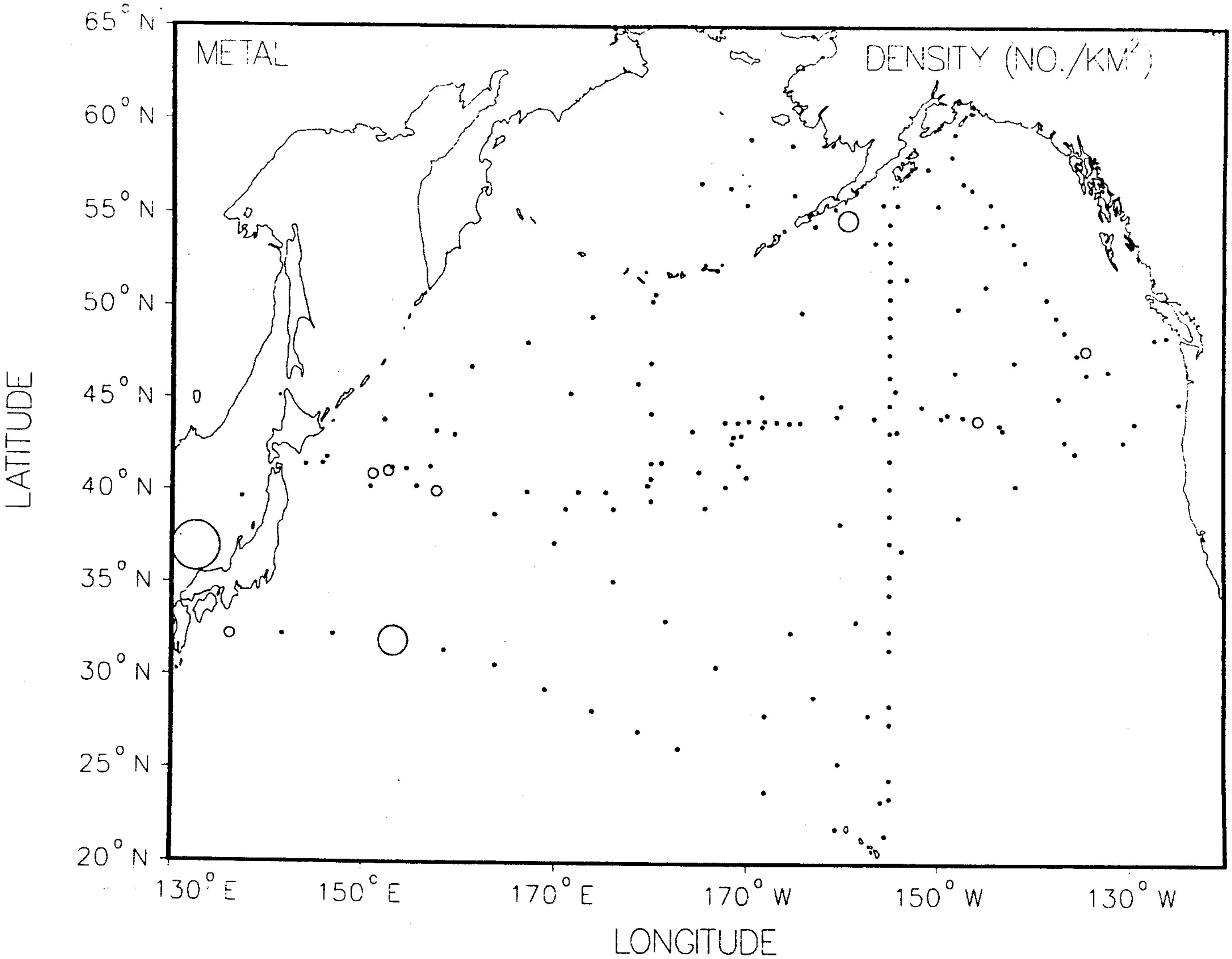


Figure 4.--Densities of metal debris, 1984-88. Solid black circles indicate stations at which metal debris was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 0.5 piece/km^2.

piece of twine. Woven debris was the least common kind of paper/fiber, being recorded seven times (13.2%); this category included cloth fragments and bags, canvas fragments and bags, and one carpet fragment. The mean dimensions of paper/fiber objects were 23.1 × 75.6 cm (n = 42 objects of known dimensions); the mean dimensions excluding objects >200 cm long were only 23.1 × 50.6 cm (n = 42 and n = 39, respectively), however.

Because paper decomposes rapidly at sea, paper/fiber debris occurred primarily near shore (e.g., the Japan Sea, off eastern Japan, the Bering

Sea) or in areas that are fished heavily (e.g., southeastern Bering Sea, flying squid fishery near the Subarctic Front east of Japan), where numerous fishing boats provide constant input of paper debris; most of the records of this debris type in southern Transitional Water and northern Subtropical Water are of hemp deck lines (Fig. 5). The highest density was 2.3 pieces/km^2 at lat. 36°55'N, long. 132°30'E in the Japan Sea. Densities of paper/fiber differed significantly among water masses ($H = 38.676$; $n = 181$; $df = 4$; $P < 0.05$; Table 1). Multiple comparisons indicated that densities were: Japan Sea/nearshore Japan Water > Transitional Water = Subtropical Water = Subarctic Water = Bering Sea Water.

Rubber Debris

Rubber objects were recorded only four times, the least of all general debris types. All four (100%) objects were rubber gloves, which frequently are used on fishing boats. The mean dimensions of rubber objects were 15.5 × 25.5 cm ($n = 3$ objects of known dimensions).

Rubber debris was recorded at only three stations: at lat. 32°15'N, long. 141°36'E in Transitional Water east of Japan; at lat. 36°55'N, long. 132°30'E in the Japan Sea; and at lat. 27°59'N, long. 157°13'W in Subtropical Water north of the Hawaiian Islands. The highest density was 0.3 piece/km^2 in the Japan Sea. Densities of rubber appeared to differ significantly among water masses ($H = 28.715$; $n = 181$; $df = 4$; $P < 0.05$; Table 1). Multiple comparisons, however, found no significant differences; we suspect that densities were too low overall for the multiple comparisons to find differences. The pattern of mean ranks (in descending order) was: Japan Sea/nearshore Japan Water, Transitional Water, and none in Subtropical, Subarctic, and Bering Sea Waters.

Wood Debris

Wood objects were recorded 68 times. Sawed or milled wood objects were the most common (63 objects; 92.6% of total wood); this category consisted (in decreasing order of frequency) of boards, sawed logs (for shipping to sawmills), dock pilings, and large timbers or blocks that frequently are used as dunnage on ships. Bamboo objects (3; 4.4%) were next in abundance and consisted of flagpoles (for marking the ends of drift gillnets) and fragments. Finally, fabricated objects (2; 2.9%) were represented by one wooden pallet and what appeared to be a wooden ladder. The mean dimensions were 23.5 × 183.0 cm ($n = 62$ objects of known dimensions); the mean dimensions excluding objects >200 cm long were 23.5 × 78.8 cm ($n = 62$ and $n = 45$, respectively), however.

Wood debris occurred primarily near shore, probably because of its tendency to become waterlogged and sink with time. The highest densities were in the northern Gulf of Alaska, where harvested logs were common in the Alaska Coastal Current and farther offshore, in the Japan Sea and off the eastern shore of Japan; little wood debris was recorded far from shore, however (Fig. 6). The highest density was 2.8 pieces/km^2 at lat. 59°47'N, long. 148°17'W near the coast of the northern Gulf of Alaska. Densities of wood differed significantly among water masses ($H = 19.830$; $n = 181$; $df = 4$; $P < 0.05$; Table 1). Multiple comparisons indicated that densities

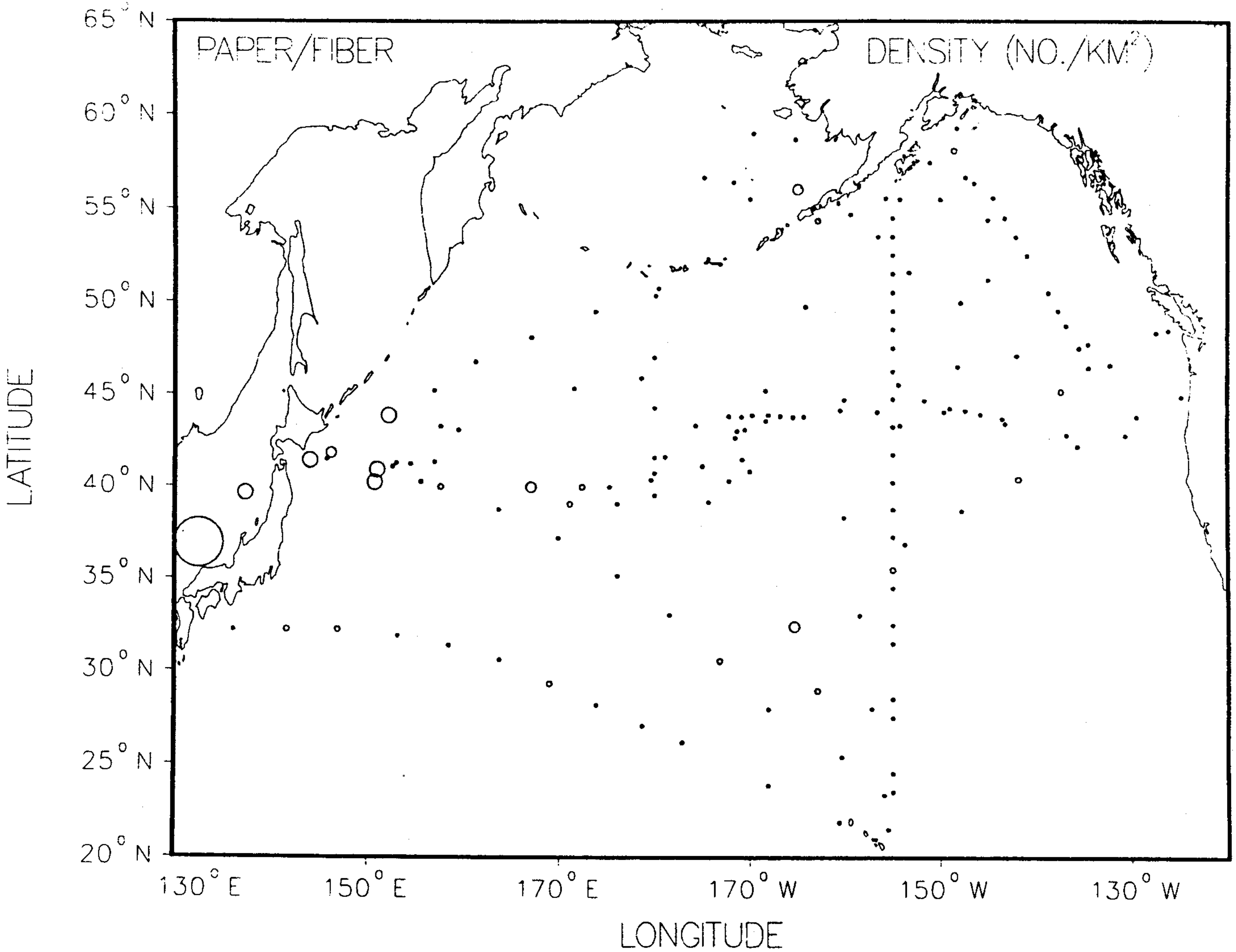


Figure 5.--Densities of paper/fiber debris, 1984-88. Solid black circles indicate stations at which paper/fiber debris was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 2.3 pieces/km².

were: Japan Sea/nearshore Japan Water > Subarctic Water = Subtropical Water = Transitional Water = Bering Sea Water.

Plastic Debris

Types of Plastic Debris

Of the 1,899 plastic debris objects recorded on transect, fragments were the most common type (649 objects). Styrofoam was next in abundance

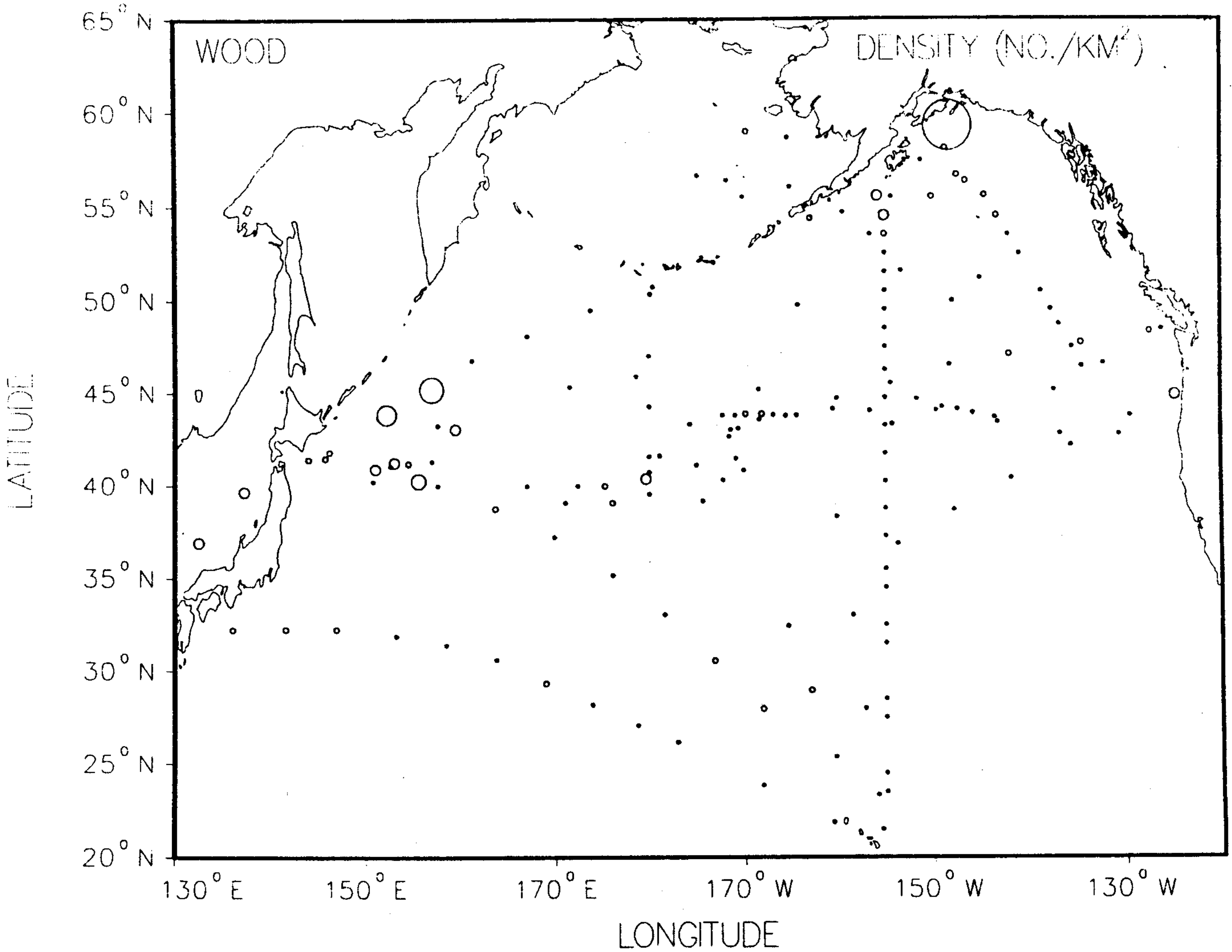


Figure 6.--Densities of wood debris, 1984-88. Solid black circles indicate stations at which wood debris was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 2.8 pieces/km^2.

(428 objects), followed by 346 sheets/bags, 95 gillnet floats, 59 polypropylene line fragments, 54 miscellaneous floats, 12 gillnet fragments (plus 8 seen off transect), 11 trawl net fragments (plus 3 seen off transect), 8 uncut plastic straps, and 3 unidentified net fragments (plus 1 seen off transect). Miscellaneous/unidentified plastic debris was recorded 234 times. The mean dimensions of plastic objects were 13.3 x 24.3 cm (n = 1,569 objects of known dimensions); the mean dimensions excluding objects >200 cm were 11.7 x 19.1 cm (n = 1,564 and n = 1,557, respectively).

As might be expected from its abundance overall, plastic debris was the most widespread of all debris types (Fig. 7). The highest densities were in the Japan Sea and off the eastern coast of Japan, with lower densities in the Subarctic Front east of Japan and in southern Transitional Water; the lowest densities were near the Hawaiian Islands, in Subarctic Water (especially in the Alaska Gyre), and in the Bering Sea. The highest density of total plastic debris was 32.6 pieces/km^2 at lat. 36°55'N, long. 132°30'E in the Japan Sea; local densities here were so high that Day was unable to census all marine debris, so he stopped sampling here. The only other high densities of plastic debris were 23.8 pieces/km^2 at lat. 41°50'N, long. 146°12'E and 18.2 pieces/km^2 at lat. 40°15'N, long. 150°46'E, both off the eastern coast of Japan. Densities of plastic differed significantly among water masses ($H = 74.168$; $n = 181$; $df = 4$; $P < 0.05$; Table 1). Multiple comparisons indicated that densities were: Japan Sea/nearshore Japan Water = Subtropical Water = Transitional Water > Subarctic Water = Bering Sea Water.

Fragments were irregular pieces of plastic (other than the specific categories discussed here) that apparently had been broken from other, larger pieces. They were the most abundant plastic type, being recorded 649 times (34.2% of total plastic). Fragments occurred in highest densities off eastern Japan and in the Japan Sea, with lower densities in northern Subtropical Water near the Subtropical Front; in contrast, they were uncommon in Subarctic Water and the Bering Sea (Fig. 8). The highest density was 18.9 pieces/km^2 at lat. 41°50'N, long. 146°12'E off the eastern coast of Japan. The density of plastic fragments differed significantly among water masses ($H = 62.887$; $n = 181$; $df = 4$; $P < 0.05$; Table 2). Multiple comparisons indicated that densities were: Japan Sea/nearshore Japan Water = Transitional Water > Subtropical Water = Subarctic Water = Bering Sea Water.

Styrofoam included all objects made of foamed polystyrene, including fragments, sheets, boxes or other containers, and fishing floats; based on observed colors and textures, we believe that none of this debris consisted of other types of foamed plastics (e.g., polyurethane). Styrofoam objects were recorded 428 times (22.5% of total plastic), making them second in abundance of all plastic types. As was seen for neuston plastic (Day et al. 1990), Styrofoam debris also is a "nearshore Japan/transitional species," with few records in Subarctic Water or the Bering Sea (Fig. 9). The highest density was 4.9 pieces/km^2 at lat. 36°55'N, long. 132°30'E in the Japan Sea. The density of Styrofoam differed significantly among water masses ($H = 58.655$; $n = 181$; $df = 4$; $P < 0.05$; Table 2). Multiple comparisons indicated that densities were: Japan Sea/nearshore Japan Water = Transitional Water = Subtropical Water > Subarctic Water = Bering Sea Water.

Polypropylene line is used more commonly than are other synthetic lines and largely has replaced hemp line on ships; consequently, we categorized all lines that appeared to be synthetic as polypropylene. Debris of this type consisted of intact lines and line fragments. Polypropylene lines were recorded 59 times (3.1% of total plastic). These lines were absent in the Bering Sea, were recorded in Subarctic Water only three times, and peaked in abundance in and around the Subarctic Front, in

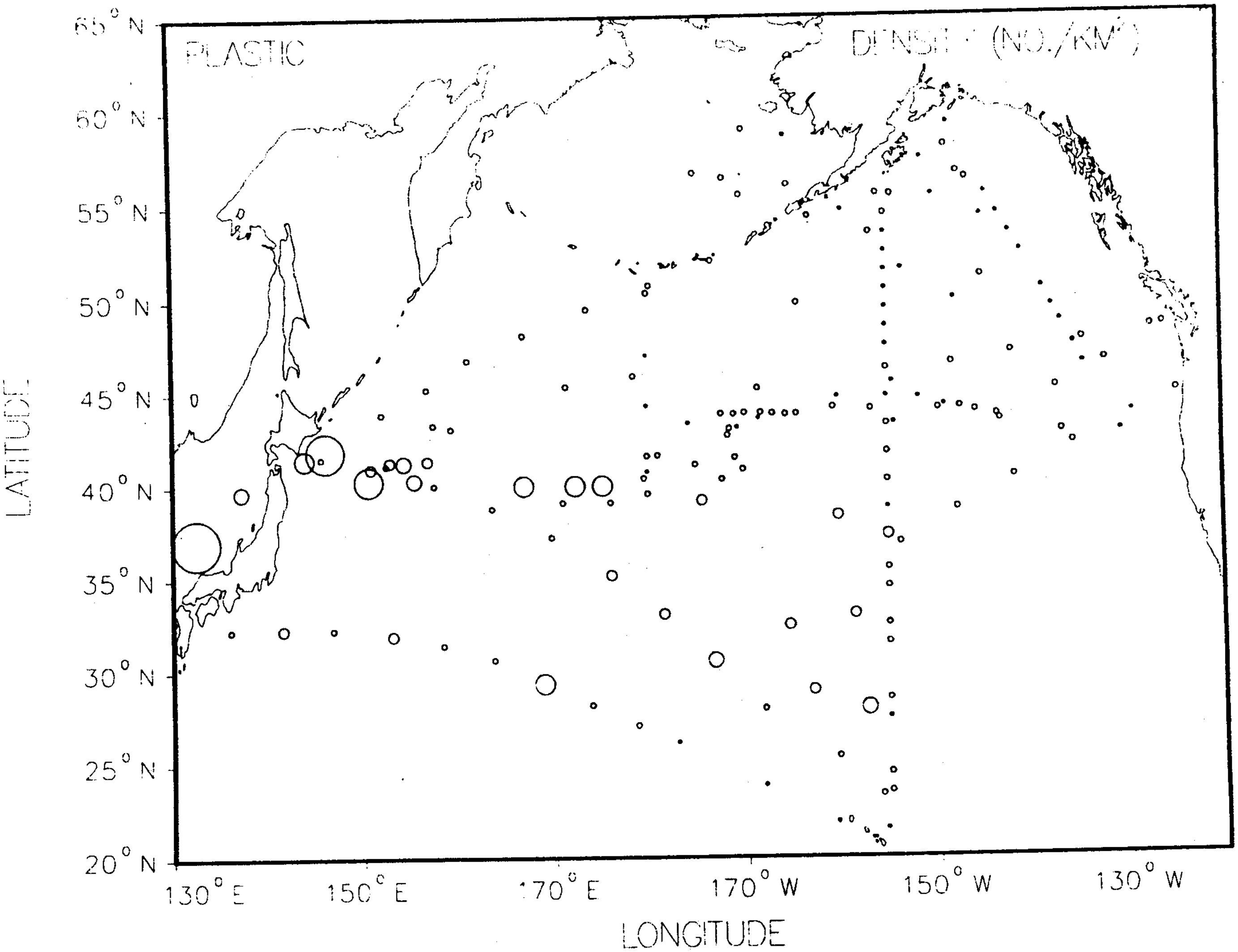


Figure 7.--Densities of plastic debris, 1984-88. Solid black circles indicate stations at which plastic debris was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 32.6 pieces/km².

the Japan Sea, and in and near the Subtropical Front (Fig. 10). The highest density was 1.2 pieces/km² at lat. 40°00'N, long. 175°17'E near the Subarctic Front in the central Pacific. Densities of polypropylene line differed significantly among water masses ($H = 27.068$; $n = 181$; $df = 4$; $P < 0.05$; Table 2). Multiple comparisons were confusing, however, in that those water masses with the largest difference in mean ranks were not significantly different, whereas water masses with smaller differences in mean ranks were significantly different. The two water masses that were significantly different were Transitional Water > Subarctic Water, the two

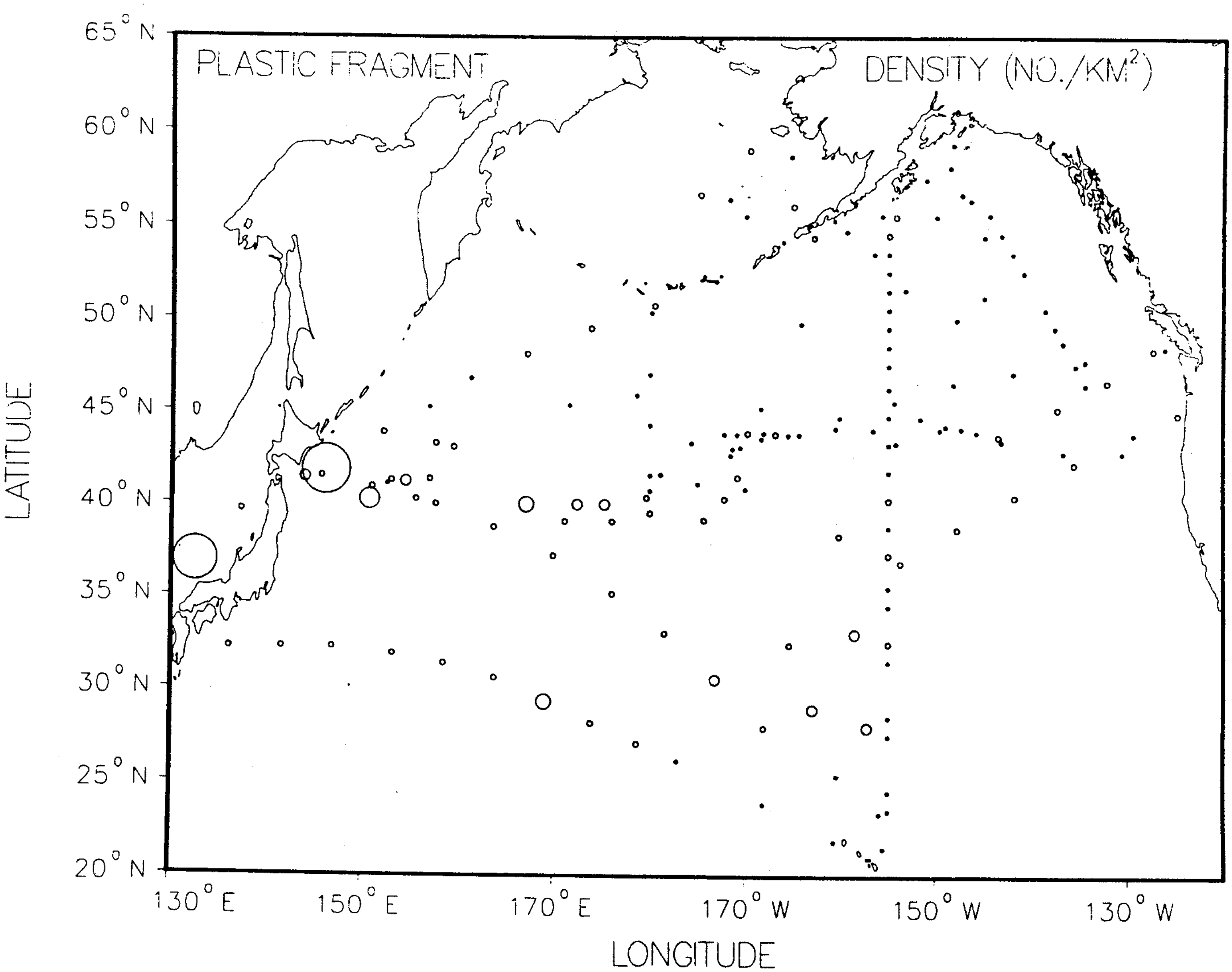


Figure 8.--Densities of plastic fragments, 1984-88. Solid black circles indicate stations at which plastic fragments was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 18.9 pieces/km².

with the largest sample sizes (49 and 99, respectively). We suspect that other water masses were different but that sample sizes in most were too small for the multiple comparisons to show significant differences. The pattern of mean ranks (in descending order) was: Transitional Water, Subtropical Water, Japan Sea/nearshore Japan Water, Subarctic Water, and Bering Sea Water.

Table 2.--Densities (number/km^2) of types of plastic debris in five water masses of the North Pacific, 1985-88.

Parameter	Bering Sea Water		Subarctic Water		Transitional Water		Subtropical Water		Japan Sea and nearshore Japan Water	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
n	7		99		49		18		8	
Fragment	0.1	0.1	0.1	0.2	0.9	1.3	0.8	1.4	5.3	7.6
Styrofoam	<0.1	0.1	0.1	0.1	0.7	0.8	0.4	0.8	2.1	1.7
Polypropylene line	0.0	0.0	<0.1	<0.1	0.1	0.2	0.1	0.2	0.2	0.4
Gillnet float	0.0	0.0	<0.1	0.1	0.2	0.2	0.2	0.3	0.1	0.1
Miscellaneous float	0.0	0.0	<0.1	<0.1	0.1	0.1	0.1	0.1	0.1	0.2
Gillnet fragment	0.0	0.0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.0	0.0
Trawl net fragment	0.0	0.0	<0.1	<0.1	<0.1	0.1	0.1	<0.1	0.0	0.0
Unidentified net fragment	0.0	0.0	0.0	0.0	<0.1	<0.1	0.0	0.0	0.0	0.0
Uncut strapping	0.0	0.0	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	0.1
Sheet/bag	<0.1	<0.1	<0.1	0.1	0.8	1.3	0.1	0.2	2.1	2.8
Miscellaneous/ unidentified	0.1	0.1	<0.1	0.1	0.5	0.5	0.3	0.4	0.6	0.5

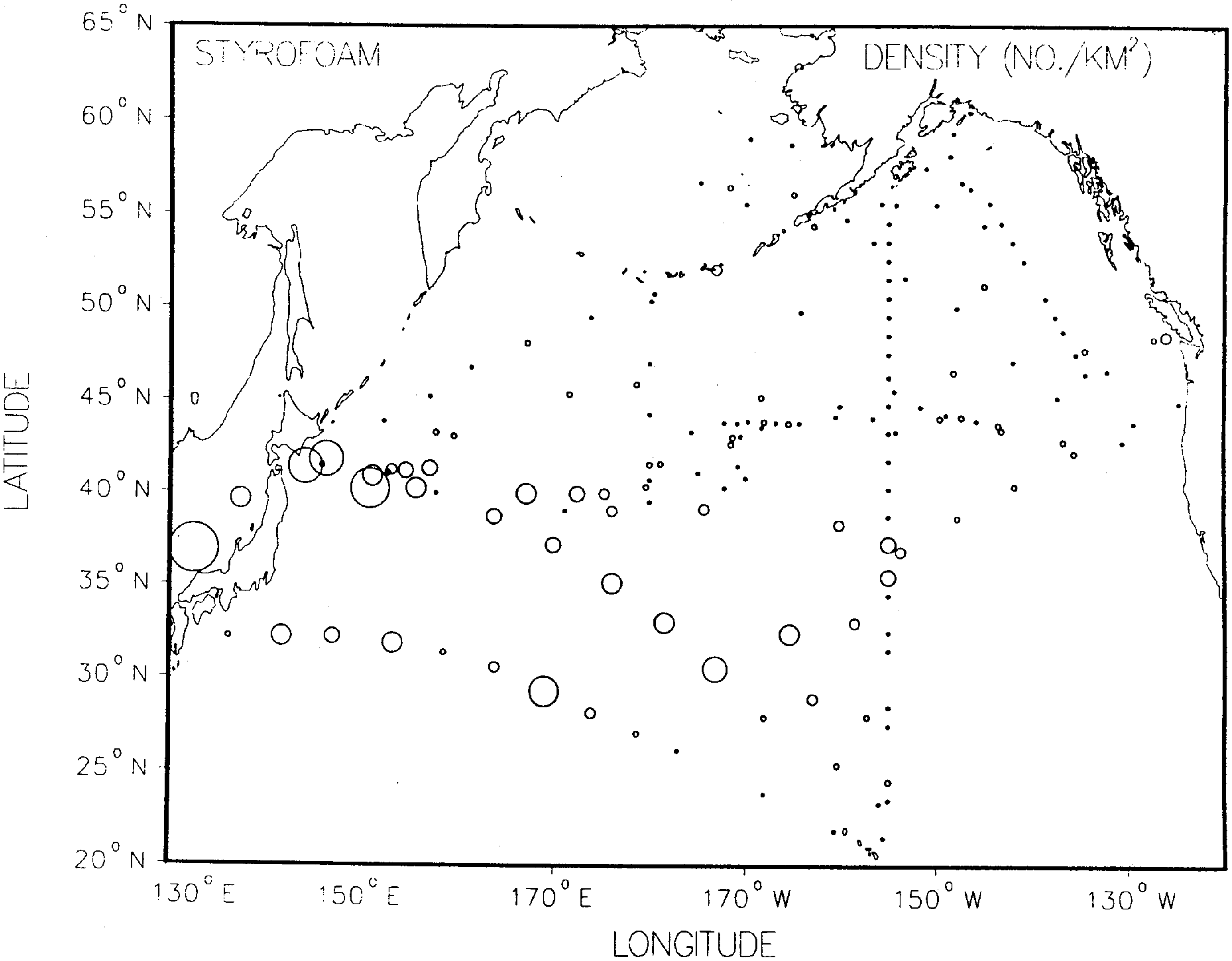


Figure 9.--Densities of Styrofoam, 1984-88. Solid black circles indicate stations at which Styrofoam was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 4.9 pieces/km^2.

Floats include gillnet floats, trawl net floats, longline floats, crab pot buoys, and large boat bumpers made out of plastic other than Styrofoam. They primarily represent various types of fishing floats.

Gillnet floats were widely distributed and were common, being recorded 95 times (5.0% of total plastic). They were especially common in and around the Subarctic Front (center of the major gillnet fishery for squid--see below), in southern Transitional Water, and in and near the Subtropical

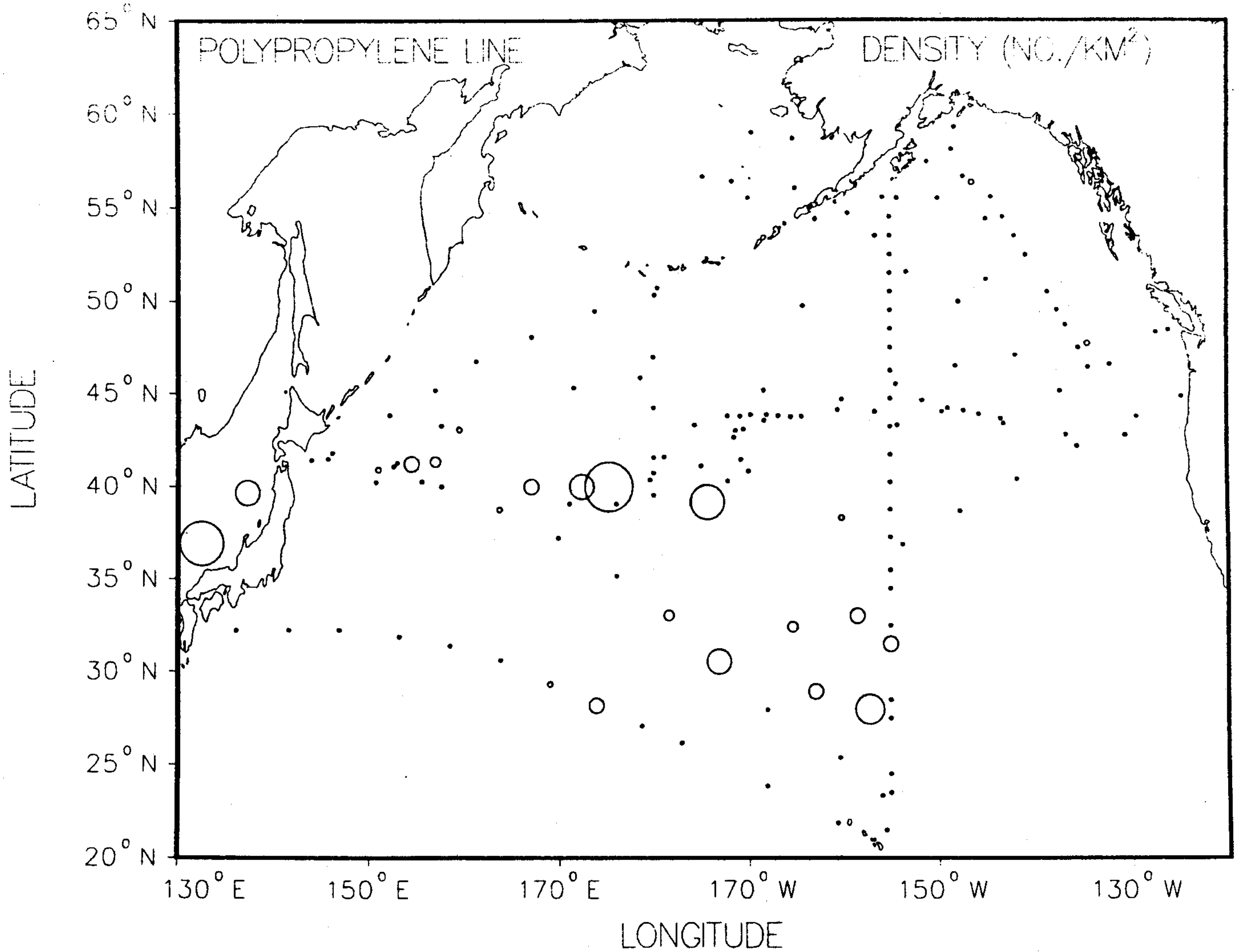


Figure 10.--Densities of polypropylene line, 1984-88. Solid black circles indicate stations at which polypropylene line was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 1.2 pieces/km².

Front; the only place they were absent was in the Bering Sea, probably because of the limited sampling there (Fig. 11). The highest density was 0.8 piece/km² at lat. 40°15'N, long. 150°46'E near the Subarctic Front east of Japan and at lat. 27°59'N, long. 157°13'W in Subtropical Water north of Hawaii. Densities of gillnet floats differed significantly among water masses ($H = 28.690$; $n = 181$; $df = 4$; $P < 0.05$; Table 2). Multiple comparisons again were confusing, however, in that those water masses with the largest difference in mean ranks were not significantly different, whereas

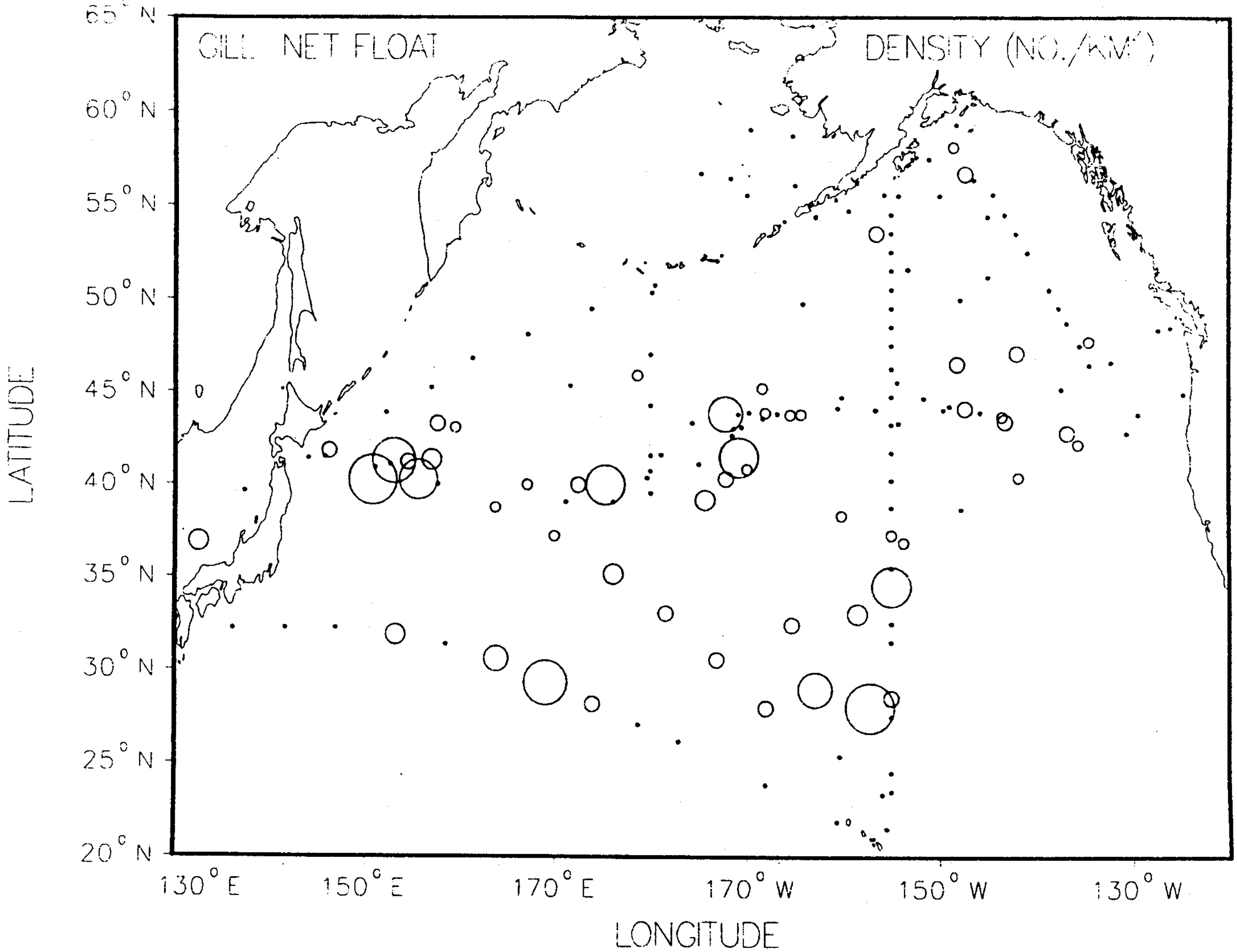


Figure 11.--Densities of plastic gillnet floats, 1984-88. Solid black circles indicate stations at which gillnet floats were not recorded. Sizes of hollow circles indicate relative densities. The highest density was 0.8 piece/km².

water masses with smaller differences in mean ranks were significantly different. The two water masses that were significantly different were Transitional Water > Subarctic Water, the two with the largest sample sizes (49 and 99, respectively). Again, we suspect that other water masses were different, but that sample sizes in most were too small for the multiple comparisons to show significant differences. The pattern of mean ranks (in descending order) was: Transitional Water, Subtropical Water, Japan Sea/nearshore Japan Water, Subarctic Water, and Bering Sea Water.

Miscellaneous floats also were widespread at sea. These floats were concentrated in southern Transitional Water and Subtropical Water, with records scattered everywhere but the Bering Sea, again probably because of the limited sampling there (Fig. 12). These floats were rare in Subarctic Water as a whole, however. The highest density was 0.6 piece/km^2 at lat. 33°01'N, long. 158°31'W in Transitional Water north of Hawaii. Densities of miscellaneous floats differed significantly among water masses ($H = 29.842$; $n = 181$; $df = 4$; $P < 0.05$; Table 2). Multiple comparisons again were confusing, in that those water masses with the largest difference in mean ranks were not significantly different, whereas water masses with smaller differences in mean ranks were significantly different. The two water masses that were significantly different were Subtropical Water > Subarctic Water; one of these water masses had a moderate sample size and the other had a large sample size (18 and 99, respectively). We again suspect that other water masses were different, but that sample sizes in most were too small for the multiple comparisons to show significant differences. The pattern of mean ranks (in descending order) was: Japan Sea/nearshore Japan Water, Subtropical Water, Transitional Water, Subarctic Water, and Bering Sea Water.

Although they were recorded only 34 times on transect and another 12 times off transect, net fragments and uncut packing straps are important components of marine debris, for they are thought to cause excessive mortality of some marine animals such as northern fur seals (Fowler 1982, 1985, 1987). These four plastic types were not distributed evenly in the North Pacific, but instead were concentrated between lat. 37° and 44°N (Fig. 13).

Gillnet fragments were recorded on transect 12 times and off transect 8 times; they were seen between lat. 25°37' and 45°15'N, with the most (3) seen at lat. 38°-39° and 42°-43°N (Fig. 13). The highest density was 0.7 piece/km^2 in Subtropical Water northwest of the Hawaiian Islands. Densities of gillnet fragments differed significantly among water masses ($H = 14.732$; $n = 181$; $df = 4$; $P < 0.05$; Table 2). Multiple comparisons, however, did not find significant differences. We suspect that densities were too low overall for the multiple comparisons to find significant differences. The pattern of mean ranks (in descending order) was: Subtropical Water, Transitional Water, Subarctic Water, and none in Japan Sea/nearshore Japan Water and Bering Sea Water.

Trawl net fragments were recorded on transect 11 times and off transect 3 times; they were seen between lat. 30°21' and 44°07'N, with the most (3) seen at lat. 40°-41° and 41-42°N (Fig. 13). The highest density was 0.2 piece/km^2, recorded at four stations near the Subarctic Front in the central and western North Pacific. Densities of trawl net fragments differed significantly among water masses ($H = 10.629$; $n = 181$; $df = 4$; $P < 0.05$; Table 2). Multiple comparisons did not find significant differences, however, and we suspect that densities were too low overall for the multiple comparisons to find significant differences. The pattern of mean ranks (in descending order) was: Transitional Water, Subtropical Water, Subarctic Water, and none in Japan Sea/nearshore Japan Water and Bering Sea Water.

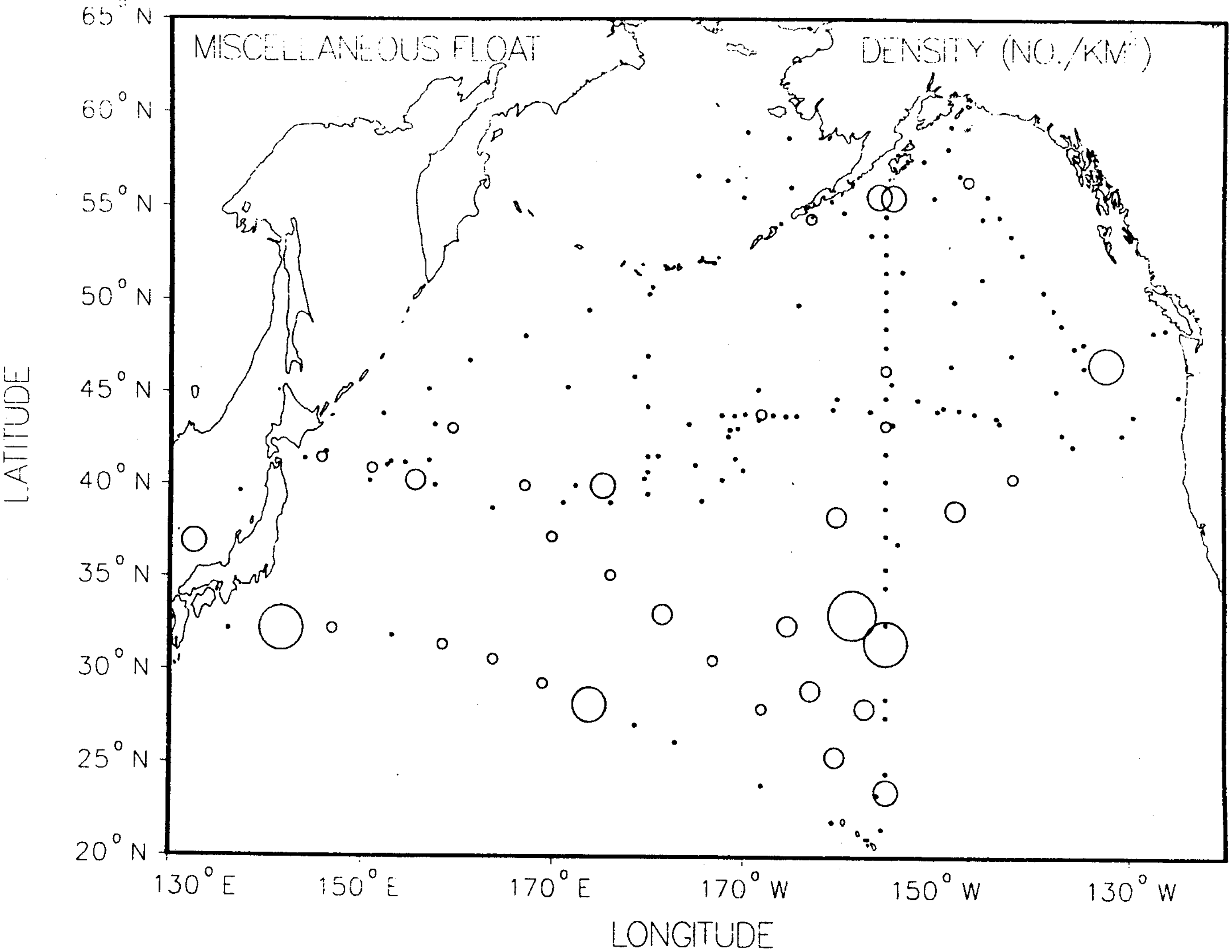


Figure 12.--Densities of miscellaneous plastic floats, 1984-88. Solid black circles indicate stations at which miscellaneous plastic floats were not recorded. Sizes of hollow circles indicate relative densities. The highest density was 0.6 piece/km².

Unidentified net fragments were recorded on transect three times and off transect once; they were seen between lat. 33°07′ and 43°35′N, with the most (two) seen at lat. 33°-34°N (Fig. 13). The estimated mesh size of these nets was 4 x 4 cm. The highest density was 0.3 piece/km² at lat. 33°01′N, long. 158°31′W in Transitional Water north of Hawaii. Densities of unidentified net fragments did not differ significantly among water masses ($H = 5.418$; $n = 181$; $df = 4$; $P > 0.05$; Table 2), probably because they were so low overall.

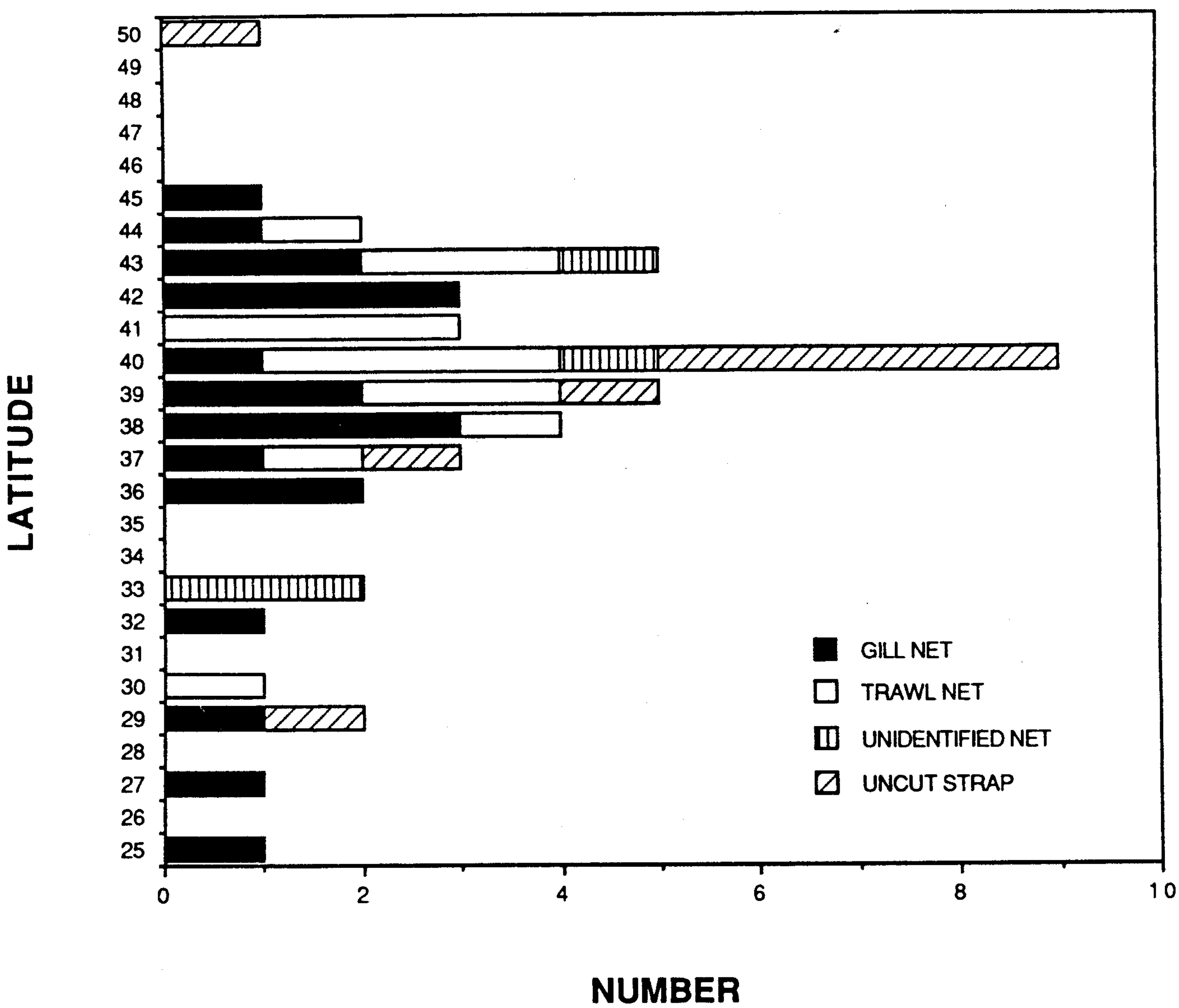


Figure 13.--Numbers of nets and uncut plastic strapping seen, by 1° blocks of latitude, 1984-88.

Uncut straps were recorded eight times, all on transect; they were seen between lat. 29°33' and 50°03'N, with the most (four) seen at lat. 40°-41°N (Fig. 13). The highest density was 0.3 piece/km² at lat. 36°55'N, long. 132°30'E in the Japan Sea. Densities of uncut straps did not differ significantly among water masses ($H = 5.462$; $n = 181$; $df = 4$; $P > 0.05$; Table 2), probably because they were so low overall.

Sheets and bags, which are a pollution problem because they are eaten by and entangle sea turtles (Balazs 1985; Carr 1987), were recorded 346 times (18.2% of total plastic). Sheets and bags occurred in highest densities in the Japan Sea, off the eastern coast of Japan, and along the Subarctic Front east of Japan; this debris type was common in Transitional Water and was essentially absent from Subarctic Water and the Bering Sea (Fig. 14). The highest density was 7.9 pieces/km² at lat. 36°55'N, long. 132°30'E in the Japan Sea. Densities of sheets/bags differed significantly among water masses ($H = 61.202$; $n = 181$; $df = 4$; $P < 0.05$; Table 2). Multiple comparisons indicated that densities were: Japan Sea/nearshore Japan Water = Transitional Water > Subtropical Water = Subarctic Water = Bering Sea Water.

Miscellaneous/unidentified plastic consisted of both fabricated objects and truly unidentified pieces; the latter objects occurred when we encountered such high local densities that we were unable to record all details on individual plastic objects. One hundred fifty-seven containers of various kinds constituted 67.1% of this category and included bottles, jars, squeeze tubes, boxes, bowls, cups, pans, beer or soda cases, woven bags, and buckets. The remaining 77 objects were a diverse assortment of screens, sponges, lids, mats, bottle caps, sandals, trays, rings, shoe liners, shovels, pipes, toys, paddles, poles, baseball caps, handles, helmets, and unidentified plastic debris. The highest density was 1.3 pieces/km² at lat. 35°10'N, long. 176°01'E in Transitional Water in the central North Pacific, at lat. 40°15'N, long. 150°46'E near the Subarctic Front off eastern Japan, and at lat. 36°55'N, long. 132°30'E in the Japan Sea.

Colors of Plastic Debris

Plastic debris was recorded in all 10 of the standardized colors, plus miscellaneous/mixed colors (Fig. 15). White was by far the most common color, being recorded 922 times (48.6% of total plastic). The color tan was second in abundance (187; 9.9%), followed by transparent (124; 6.5%), blue (119; 6.3%), and yellow (86; 4.5%). The colors green (35; 1.8%), brown (32; 1.7%), red/pink (28; 1.5%), black/gray (25; 1.3%), and orange (17; 0.9%) were rare in occurrence. Finally, miscellaneous/mixed plastic was recorded 323 times (17.0% of total plastic), primarily in cases when local densities were too high for us to record all data on individual pieces of debris.

Frequencies of some colors of debris plastic differed strongly from those frequencies of neuston plastic (Fig. 15). The greatest difference was in transparent plastic, whose frequency in marine debris was <25% of that in neuston plastic. Similarly, the frequency of black and gray plastic in marine debris was <50% of that in neuston plastic. In

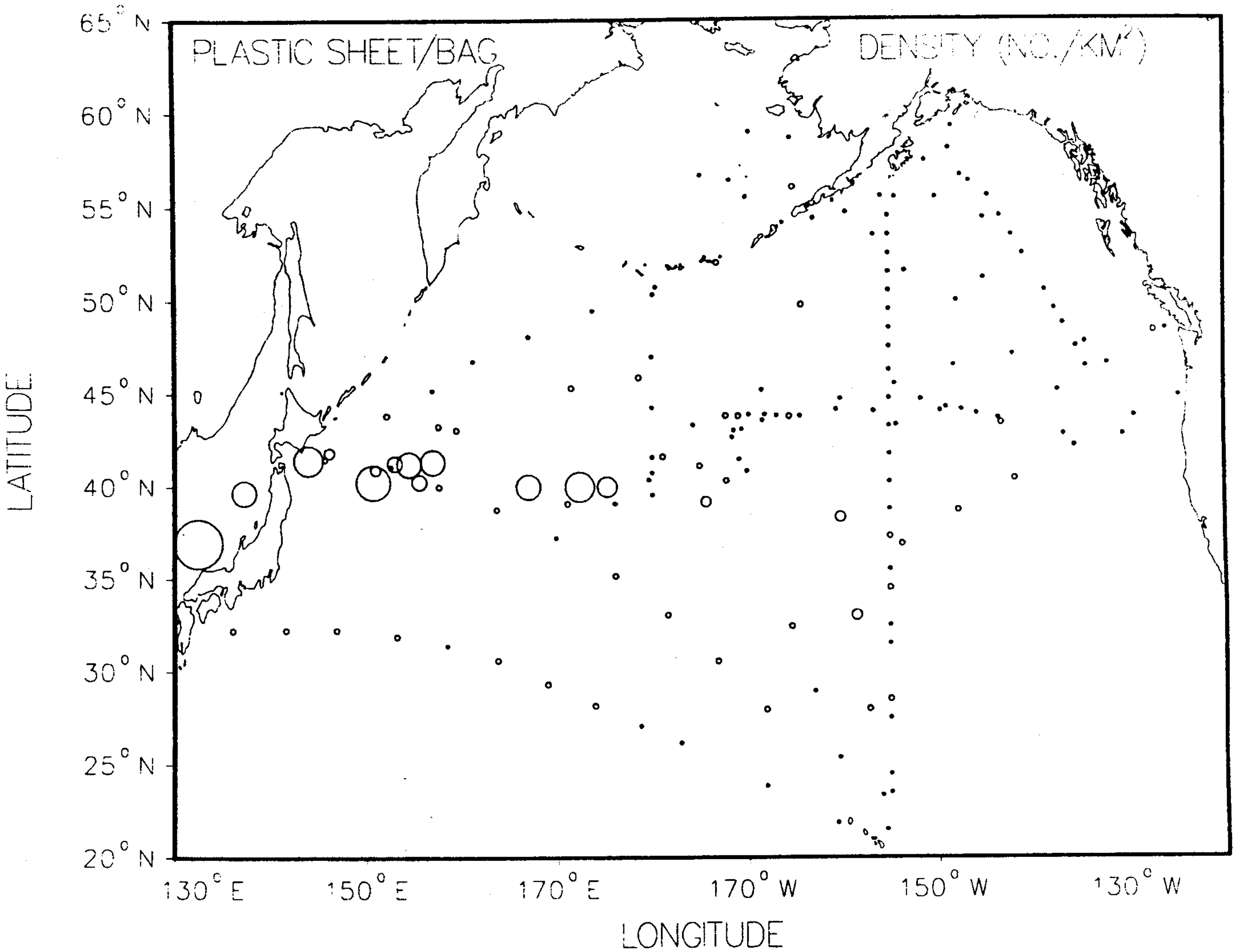


Figure 14.--Densities of plastic sheets and bags, 1984-88. Solid black circles indicate stations at which plastic sheets and bags were not recorded. Sizes of hollow circles indicate relative densities. The highest density was 7.9 pieces/km².

contrast, the frequency of white plastic was nearly 33% higher, that of tan plastic was nearly four times higher, and that of yellow plastic was nearly four times higher in marine debris than in neuston plastic. Frequencies of the other colors were relatively similar comparing the two types of plastic.

DISCUSSION

We believe that the present distribution of marine debris is controlled largely by four main phenomena: (1) the heterogeneous geographic

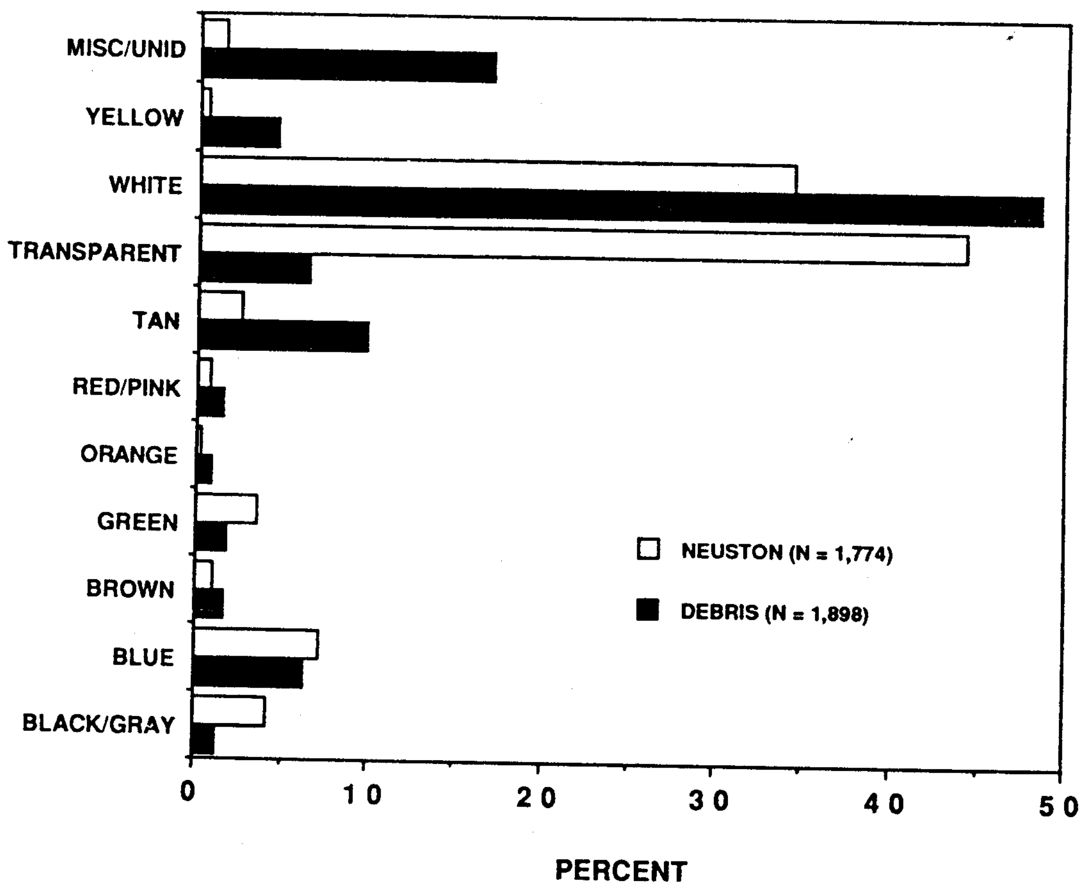


Figure 15.--Frequencies of colors of plastic debris, 1984-88, compared with frequencies of colors of neuston plastic, 1985-88 (the latter data from Day et al. 1990).

input of debris, (2) the subsequent redistribution of that debris by currents and winds, (3) the decomposition of the debris at sea, and (4) the beaching of the debris. The data that we report on here strongly suggest that these factors interact to yield the distributions that we observed. In the absence of precise data on rates of input, transport, and degradation, however, our conclusions about factors controlling marine debris in the North Pacific must be considered tentative.

It is clear that there is heterogeneous geographic input of marine debris, with much originating in the far western Pacific. This conclusion is supported strongly by the high densities in and around the Japan Sea and nearshore Japan, where the highest densities of both marine debris and neuston plastic (Day et al. 1990) in the North Pacific were recorded. Debris was most abundant in Tokyo Bay (which had far more debris than Day has ever seen elsewhere in the North Pacific--it was too abundant for him to sample) and in localized areas in the Japan Sea. It is unclear to us how much of this debris comes from ships and how much comes from the land. At the other extreme were the Bering Sea and Gulf of Alaska, where low human populations probably provide little input of marine debris.

In Transitional Water to the east of Japan, the importance of transport compared to direct input from ships is difficult to evaluate. The area between lat. 35° and 45°N and from the eastern coast of Japan to long. 145°W is the site of a large pelagic fishery for neon flying squid, *Ommastrephes bartrami*. At the height of the fishery (May-December), approximately 700 gillnetting ships from Japan, Korea, and Taiwan participate (Fredin 1985), as well as an unknown number of small jigging ships. This fishery undoubtedly contributes to marine debris in the area, although its contribution relative to transport is unknown. In contrast, debris entering the ocean around Japan and Korea is moved eastward by the Subarctic Current (in Subarctic Water) and in the Kuroshio (Kawai 1972; Favorite et al. 1976; Nagata et al. 1986) into the same area. In addition to this general eastward movement, Ekman (wind) stress tends to move surface waters from the Subarctic and the Subtropic into the Transitional Water mass as a whole (Roden 1970). As a result, densities of debris in Transitional Water generally are high, but the relative importance of the two sources (i.e., local input and transport into the area) is unclear. Further, the generally convergent nature of surface water in the North Pacific Central Gyre (Masuzawa 1972) should result in high densities there also.

Surprisingly, there are differences among the distributions of types of debris. For example, Styrofoam debris clearly is a "nearshore Japan/transitional/subtropical species" (Fig. 9); neuston Styrofoam also is most abundant around Japan (Day et al. 1990). This localized distribution of Styrofoam may be a consequence of its weak, crumbly texture, which can lead to rapid disintegration; hence, it probably cannot survive long enough to be transported offshore in large quantities. Further, Styrofoam sinks when crushed and waterlogged. Thus, it may be observed only in places where input rates are high. In addition, plastic sheets and bags also seem to be "transitional" (Fig. 14), placing them directly in the range of most of the world's sea turtle species, which readily ingest this type of plastic debris (Balazs 1985). The reason for this distribution of sheets and bags is not known.

The comparison of frequencies of colors of neuston plastic and debris plastic (Fig. 15) suggests a bias in our sampling. Colors that do not contrast strongly with seawater (black/gray, transparent) are underrepresented in debris in comparison with neuston plastic. Although some bias in the color frequency data for neuston plastic probably results from color-selective ingestion of neuston plastic by seabirds (Day et al. 1985), we believe that the difficulty in observing low-contrast debris is the major cause of the differences in Figure 15. Although there is bias in the debris sighting data, however, densities of debris plastic and neuston plastic are strongly correlated (Day and Shaw 1987). Hence, although absolute estimates of at-sea densities of marine debris plastic are affected by these sighting biases, the debris data presented here provide important information about relative abundances in various parts of the ocean.

Although Fowler (1982, 1985, 1987) claimed that entanglement in lost netting and other marine debris is the major source of mortality of northern fur seals, we find that the data on at-sea densities of lost net fragments are inadequate to determine quantitatively its true importance. We have seen fur seals entangled in net fragments only twice, both in the flying squid fishery and both during fall 1987. The first record was of a fur seal with a trawl net fragment caught over its head at lat. 44°07'N, long. 156°23'W; there were raw, open cuts on the face and gums, although this animal did not appear to be hurt in any way and swam playfully with another unentangled fur seal. The second record was of an immature female fur seal completely entangled in a gillnet fragment at lat. 43°15'N, long. 145°11'W, along with the partially eaten remains of what appeared to be a salmon shark, *Lamna ditropis*, and a yellowtail, *Seriola lalanda*. Thus, sightings of entangled fur seals in derelict net fragments at sea are quite rare, making it difficult to assess the frequency of entanglement. On the other hand, our extensive experience at sea in the North Pacific suggests to us that the probability of entanglement and subsequent mortality of fur seals is higher in nets that actively are fishing for flying squid than in net fragments. The flying squid fishery deploys approximately 3,000,000 km of drift gillnets annually and is concentrated approximately in the zone lat. 39°-46°N (Day unpubl. data). Further, many of the deployments of research nets observed by Day in this area resulted in fur seals' feeding from the nets, climbing on and swimming around the nets, and occasionally becoming caught in the nets. (Most escaped unharmed, however.) Given the high number of entanglements of fur seals in actively fishing gillnets that we have observed, the nearly 60,000 vessel-nights of net deployments in a year, the large amounts of those nets that are fished, and the low number of entanglements in lost net fragments that we have observed in over 21,000 km of observations at sea, we suggest here that the mortality of fur seals from actively fishing nets should be assessed quantitatively and compared to estimates of mortality from derelict nets.

ACKNOWLEDGMENTS

Most of this research was done while Day was an Angus Gavin Memorial Fellow, a Sea Grant Fellow, or a Resources Fellow at the University of Alaska. Additional funding came from the National Marine Fisheries Service (NMFS), NOAA (contracts 40ABNF63228 and 43ABNF702983) and two contracts from the Joint Institute for Marine and Atmospheric Research at the University of Hawaii. Data were collected aboard the TV *Oshoro Maru* of Hokkaido University, Hakodate, Japan; RV *Pusan 851* of the National Fisheries Research and Development Agency, Government of the Republic of Korea, Pusan, Korea; RV *Miller Freeman* of the Northwest and Alaska Fisheries Center, NMFS, Seattle, Washington; RV *Akademik Korolev* of the Far Eastern Regional Institute of Goskomgidromet, Government of the Soviet Union, Vladivostok, U.S.S.R.; and RV *Alpha Helix* of the Institute of Marine Sciences, University of Alaska, Fairbanks, Alaska. We thank the captains, officers, and crews of these ships for assistance. This manuscript was improved by comments of three anonymous reviewers. This is Contribution No. 828 of the Institute of Marine Sciences, University of Alaska, Fairbanks, Alaska.

REFERENCES

Baba, N., K. Yoshida, M. Onoda, N. Nagai, and S. Toishi.
1986. Research on ocean current and drifting stray fishing gear and net fragments in the area to the southwest of the Pribilof Islands and the southern coast of the Aleutian Islands July-August, 1985. Far Seas Fisheries Research Laboratory, Shimizu, Japan, 15 p. Document submitted to the Standing Scientific Committee of the North Pacific Fur Seal Commission.

Balazs, G. H.
1985. Impact of ocean debris on marine turtles: Entanglement and ingestion. *In* R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii, p. 387-429. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54.

Carr, A.
1987. Impact of non-degradable marine debris on the ecology and survival outlook of sea turtles. Mar. Pollut. Bull. 18:352-356.

Conover, W. J.
1980. Practical nonparametric statistics, 2d ed. Wiley, N.Y., 493 p.

Dahlberg, M. L., and R. H. Day.
1985. Observations of man-made objects on the surface of the North Pacific Ocean. *In* R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii, p. 198-212. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54.

Day, R. H., and D. G. Shaw.
1987. Patterns in the abundance of pelagic plastic and tar in the North Pacific Ocean, 1976-1985. Mar. Pollut. Bull. 18:311-316.

Day, R. H., D. G. Shaw, and S. E. Ignell.
1990. Quantitative distribution and characteristics of neuston plastic in the North Pacific, 1985-88. *In* R. S. Shomura and M. L. Godfrey (editors), Proceedings of the Second International Conference on Marine Debris, 2-7 April 1989, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-154. [See this document.]

Day, R. H., D. H. S. Wehle, and F. C. Coleman.
1985. Ingestion of plastic pollutants by marine birds. *In* R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii, p. 344-386. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54.

DeGange, A. R., and T. C. Newby.
1980. Mortality of seabirds and fish in a lost salmon driftnet. Mar. Pollut. Bull. 11:322-323.

Favorite, F., A. J. Dodimead, and K. Nasu.
1976. Oceanography of the subarctic Pacific region, 1960-71. Int. North Pac. Fish. Comm., Bull. 33:1-187.

Fowler, C. W.
1982. Interactions of northern fur seals and commercial fisheries. Trans. N. Am. Nat. Resour. Conf. 47:278-292.

1985. An evaluation of the role of entanglement of population dynamics of northern fur seals on the Pribilof Islands. *In* R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii, p. 291-307. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54.

1987. Marine debris and northern fur seals: A case study. Mar. Pollut. Bull. 18:326-335.

Fredin, R. A.
1985. Fishing effort by net fisheries in the North Pacific Ocean and Bering Sea since the 1950's. *In* R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii, p. 218-251. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54.

Jones, L. L., and R. C. Ferrero.
1985. Observations of net debris and associated entanglements in the North Pacific Ocean and Bering Sea, 1978-84, *In* R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii, p. 183-196. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54.

Kawai, H.
1972. Hydrography of the Kuroshio Extension. *In* H. Stommel and K. Yoshida (editors), Kuroshio: Physical aspects of the Japan Current, p. 235-352. Univ. Wash. Press, Seattle, WA.

Masuzawa, J.
1972. Water characteristics of the North Pacific Central Region. *In* H. Stommel and K. Yoshida (editors), Kuroshio: Physical aspects of the Japan Current, p. 95-127. Univ. Wash. Press, Seattle, WA.

Merrell, T. R., Jr.
1980. Accumulation of plastic litter on beaches of Amchitka Island, Alaska. Mar. Environ. Res. 3:171-184.

1984. A decade of change in nets and plastic litter from fisheries off Alaska. Mar. Pollut. Bull. 15:378-384.

Mio, S., and S. Takehama.
1987. Estimation of distribution of marine debris based on the 1986 sighting survey. Fisheries Agency of Japan, Tokyo, Japan, 16 p. Document submitted to the Annual Meeting of the International North Pacific Fisheries Commission, Vancouver, Canada.

Nagata, Y., J. Yoshida, and H.-R. Shin.
1986. Detailed structure of the Kuroshio Front and the origin of the water in warm-core rings. Deep-Sea Res. 33:1509-1526.

Pruter, A. T.
1987. Sources, quantities, and distribution of persistent plastics in the marine environment. Mar. Pollut. Bull. 18:305-310.

Roden, G. I.
1970. Aspects of the mid-Pacific Transition Zone. J. Geophys. Res. 75:1097-1109.

Shomura, R. S., and H. O. Yoshida (editors).
1985. Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54, 580 p.

Venrick, E. L., T. W. Backman, W. C. Bartram, C. J. Platt, M. S. Thornhill, and R. E. Yates.
1973. Man-made objects on the surface of the central North Pacific Ocean. Nature (Lond.) 241(5387):271.

Wolfe, D. A. (guest editor).
1987. Special issue: Plastics in the sea. Mar. Pollut. Bull. 18:303-365.

Yagi, N., and M. Nomura.
1987. Sighting survey on marine debris in the midwestern Pacific from 1977 through 1986. Fisheries Agency of Japan, Tokyo, Japan, 12 p. Document submitted to the Annual Meeting of the International North Pacific Fisheries Commission, Vancouver, Canada.

Yoshida, K., and N. Baba.
1985. Results of the survey on drifting fishing gear or fish net pieces in the Bering Sea. Far Seas Fisheries Research Laboratory, Shimizu, Japan, 12 p. Document submitted to the 28th Meeting of the Standing Scientific Committee of the North Pacific Fur Seal Commission, 4-12 April 1985, 13 p.

Zar, J. H.
1984. Biostatistical analysis, 2d ed. Prentice-Hall, Englewood Cliffs, NJ, 718 p.

DISTRIBUTION AND DENSITY OF FLOATING OBJECTS IN THE NORTH PACIFIC BASED ON 1987 SIGHTING SURVEY

Shin-ichi Mio*
National Research Institute of Far Seas Fisheries
Fisheries Agency, the Government of Japan
Shimizu-shi, Shizuoka, 424 Japan

Shuichi Takehama
Division of Fishing Ground Environment Conservation
Fisheries Agency, the Government of Japan
Chiyoda-ku, Tokyo, 100 Japan

and

Satsuki Matsumura
National Research Institute of Far Seas Fisheries
Fisheries Agency, the Government of Japan
Shimizu-shi, Shizuoka, 424 Japan

*Present address: Japan Sea National Fisheries Research Institute, Fisheries Agency, the Government of Japan, Niigata-shi, Niigata, 951 Japan

ABSTRACT

A sighting survey has been conducted in the North Pacific since 1986 to understand the distribution of floating objects there. The survey was conducted on board various types of vessels, including a fisheries research vessel, patrol vessels, training vessels, and commercial freighters, a total of 32 vessels with a distance surveyed of 165,288 nmi.

A total of 46,706 floating objects were recorded in 1987. Of these, fishing net debris accounted for 0.7%, other fishing gears 5.9%, Styrofoam 14.0%, and other petrochemical products 18.3%. The remainder included drifting logs or lumber 7.9%, floating seaweed 42.7%, and other 10.5%.

Density of the objects was generally high in the coastal waters, but high density was also observed in areas between lat. 25° and 30°N, and long. 170° and 130°W. It is assumed that floating objects transported from various areas by ocean currents accumulated here. A belt-shaped low-density area was observed between lat. 45° and 50°N.

In R. S. Shomura and M. L. Godfrey (editors), Proceedings of the Second International Conference on Marine Debris, 2-7 April 1989, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-154. 1990.

INTRODUCTION

A total of 32 vessels, vessels which belong to the Fisheries Agency of the Government of Japan, training ships of fishery high schools and universities, and cargo transport ships, participated in a sighting survey of floating objects in the North Pacific (Table 1). The total distance for which the sightings were conducted was 165,228 nmi, and 46,706 items of marine debris were sighted during the cruises.

This survey has been repeated continuously since 1986, with the objectives of defining patterns of marine debris, clarifying the conditions of distribution, and determining the actual volume of various types of debris floating in the sea. Although the areas surveyed extended to the Sea of Japan, Yellow Sea, South Pacific Ocean, and Gulf of Mexico, this report concentrates on the North Pacific and its adjacent waters.

METHODS

Methods of sighting and items of observation were the same as in the previous year (Mio and Takehama 1987), except for the addition of the size of debris items observed. Size is described as follows. We measured with the eye the length of the longest piece of marine debris and recorded that S = <50, M = 50-200, and L = >200 cm.

RESULTS

Outline of Results

The distribution pattern of the cruising distance for the surveys (henceforth referred to as effort) shows that effort was high in Japanese waters and in the western Pacific, and low in the eastern and southern Pacific (Fig. 1). By season, 57.7% of the entire effort was expended during the 4 months from June to September. In the other months, excluding December, 4 to 8% of the effort was expended.

Looking at marine debris by kind (Table 2), 310 pieces of fishing net were recovered, 0.7% of all marine debris found (gillnet 0.2%, trawl net 0.1%, and unidentified net 0.4%). The proportion of fishing gears other than nets was somewhat larger (5.9%) and accounted for 15.3% of the total petrochemicals (fishing nets, other fishing gears, Styrofoam, and other plastic debris). Styrofoam accounted for 36% of all petrochemicals and for 14% of all marine debris, being the most abundant single material. Sheets and bags made of nylon and vinyl, and other plastic debris represented by containers for detergent and drinking water, accounted for 18.3% of the total marine debris and for 47.0% of the total petrochemicals. The number of their sightings was large, and they were quantitatively the major item of marine debris. Among biodegradable marine debris, pieces of wood and drifting logs accounted for 7.9%, and floating seaweed accounted for 42.7%. Other consisted mainly of glass products and empty cans, and accounted for 10.5%.

Table 1.--Vessels engaged in marine debris sighting survey in 1987.

Name of vessel	Gross tonnage	Horsepower	Area of survey[a]	Cruising distance (nmi)	Number of debris pieces sighted
Kotaka Maru	47	235	J	648.9	2,319
Tankai Maru	157	900	J	2,758.8	296
Hokko Maru	466	1,800	J P	9,435.1	971
Wakataka Maru	170	540	J	3,618.9	1,325
Soyo Maru	494	1,600	J	6,286.1	3,221
Yoko Maru	499	1,600	J	5,363.6	1,341
Mizuho Maru	150	900	J	4,979.2	3,094
Shunyo Maru	393	2,600	J	7,156.6	1,340
Shoyo Maru	1,362	2,000	J P	14,857.4	2,798
Kaiyo Maru	2,644	3,800	J P	9,940.2	179
Wakatake Maru	427	1,500	J P	4,166.7	259
Shin Riasu Maru	471	1,400	J P	12,194.9	910
Wakasio Maru	199	900	J	1,285.3	448
Hoyo Maru No. 12	284	1,000	J P	4,134.4	663
Kanki Maru No. 58	96	470	J P	4,337.7	229
Hokuho Maru	441	1,300	J P	7,281.7	654
Shirafuji Maru	138	1,000	J	386.0	876
Osyoro Maru	1,779	3,200	J P	4,018.5	166
Hoksei Maru	893	2,100	J P	4,057.2	236
Tansu Maru	444	1,500	J	1,561.9	779
Omi Maru	417	1,300	J P	4,485.1	107
Shirahagi Maru	366	2,600	J P	6,903.4	305
Toko Maru	1,513	8,000	J P	12,845.6	343
Hakuryu Maru	517	2,500	J P	4,086.7	230
Coop	2,445	3,800	J	1,237.6	52
Sunbelt Dexie	11,447	14,000	J P	5,366.6	15,387
Nichiyo Maru	995	3,000	J P	1,176.7	4,673
Kumamoto Maru	380	1,600	J	3,599.2	598
Riasu Maru No. 1	476	1,100	J P	11,732.4	251
Hoyo Maru No. 78	300	440	J P	5,294.1	885
Taisei Maru No. 55	350	3,400	J P	725.2	449
Tosi Maru No. 15	730	3,600	J	3,803.5	1,974

[a]J - Japanese waters north of lat. 20°N and west of long. 160°E;
P - Pacific area other than Japanese waters.

Effects of Environmental Conditions

In order to study the effects of luminous intensity and waves on the sighting survey, the numbers of sightings by wind force and by time of day were examined comparatively for eight vessels which had conducted surveys for a fairly long time in the area where the effort expended was largest (lat. 40° to 45°N and long. 140° to 150°E).

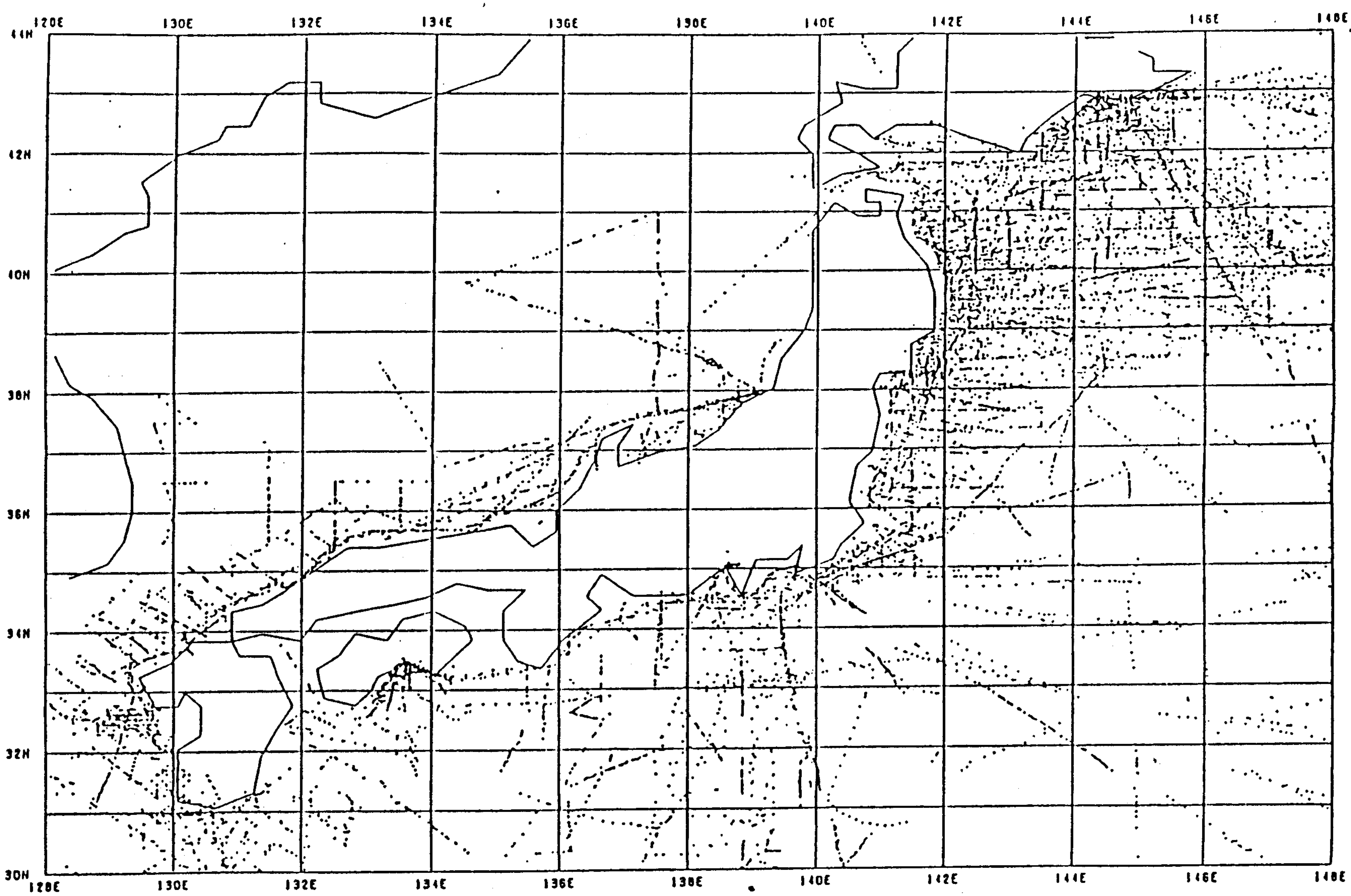


Figure 1A.--Tracks of vessels engaged in marine debris sighting survey in 1987, coastal waters of Japan.

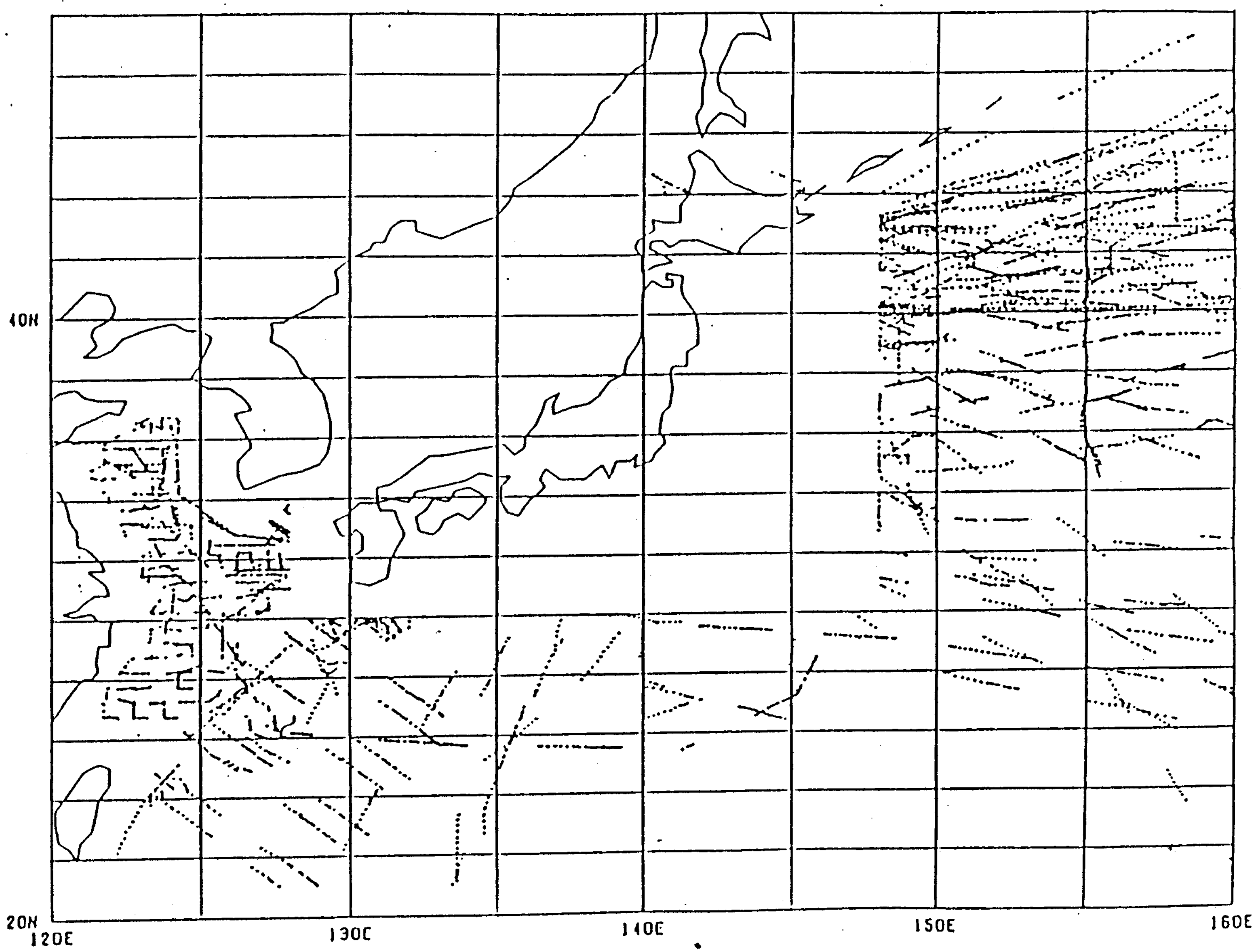


Figure 1B.--Tracks of vessels engaged in marine debris sighting survey in 1987, neighboring waters of Japan.

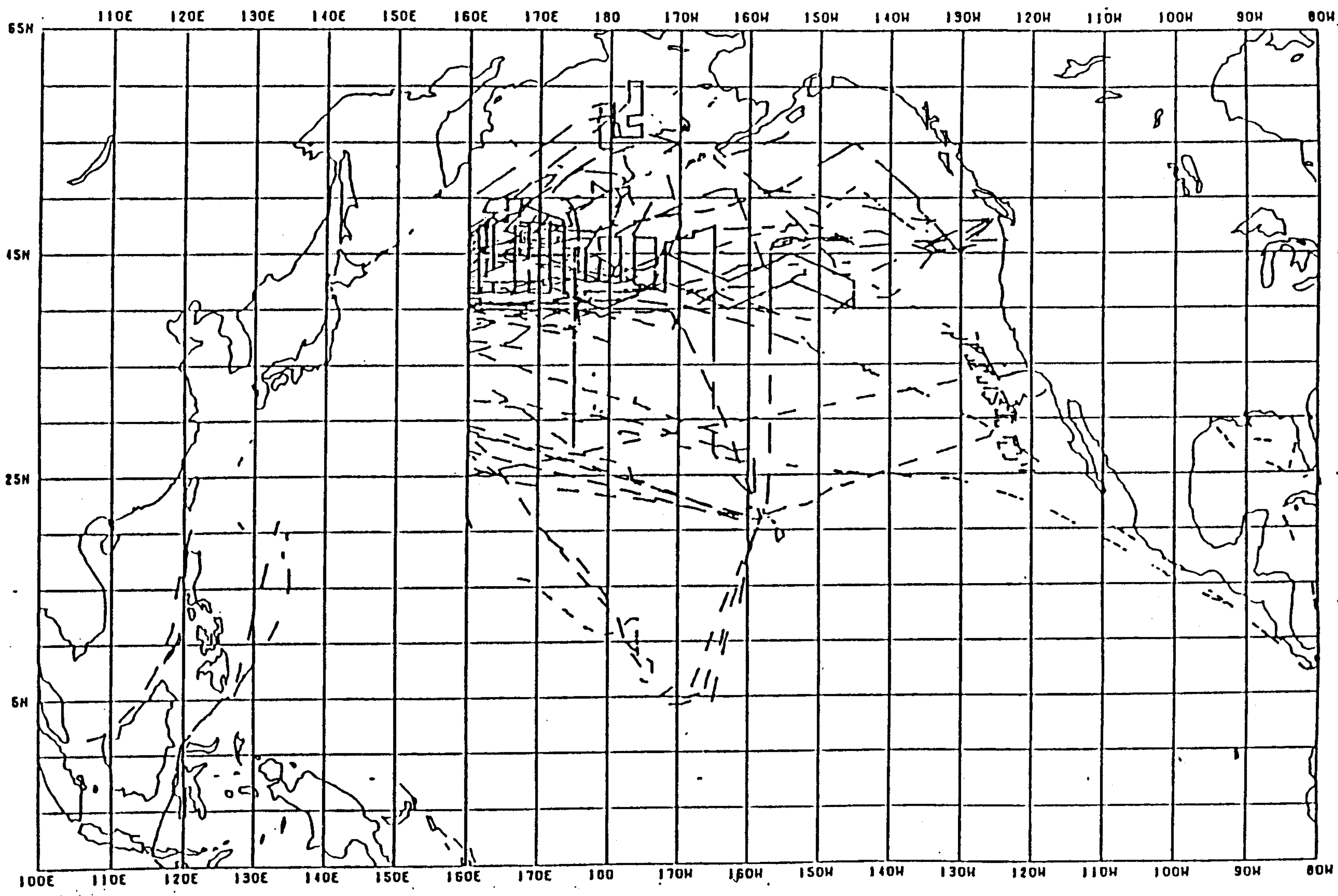


Figure 1C.--Tracks of vessels engaged in marine debris sighting survey in 1987, Pacific high seas area.

Table 2.--Number of debris items sighted, by month and type of debris.

Month	Cruising distance (nmi)	Type of debris: Fishing net									
		Unknown	Trawl	Gill	Other fishing gear	Styrofoam	Other plastic debris	Wood	Floating seaweed	Others	Total
January	7,857.3	--	--	--	18	30	12	192	169	151	582
February	7,832.1	4	--	2	38	128	85	34	32	31	354
March	8,813.8	2	--	--	104	415	115	88	709	394	1,827
April	6,819.6	4	2	5	134	360	208	207	884	62	1,875
May	11,181.7	4	2	2	169	334	131	90	257	221	1,210
June	28,435.9	13	14	7	313	752	1,020	1,172	2,192	833	6,617
July	31,323.2	23	5	6	344	724	958	314	1,601	296	4,266
August	20,184.3	19	8	9	315	873	799	295	781	309	3,408
September	18,743.9	44	25	14	567	1,136	1,500	507	4,951	627	9,371
October	13,030.9	31	3	19	282	1,162	2,761	612	7,987	1,784	14,641
November	9,840.1	27	1	13	459	541	901	141	374	162	2,619
December	1,225.2	2	--	--	31	97	59	20	14	13	236
Total	165,287.9	173	60	77	2,774	6,552	8,544	3,672	19,951	4,893	46,706

Wind Force

The evidence suggests that the number of debris items sighted per unit of effort (100 nmi) is inversely related to wind force (Beaufort scale). The maximum sightings occurred at wind force class 1 and sightings decreased as the wind force increased (Fig. 2).

Only five vessels conducted sightings surveys in wind force class 1. This effort was extremely small compared to the effort in wind force classes 2 to 5, and was only 11% of wind force class 3, which had the largest effort. Wind force which showed maximum effort varied by vessel; in the case of *Shoyo Maru*, wind force exceeding class 6 showed maximum effort. Although as a general trend the number of sightings decreased as wind force increased, the number of sightings also varied by type of vessel and kind of marine debris.

Luminous Intensity

Time of day was used as an index of luminous intensity, and data from the same time of day were compared for sighting of marine debris (Fig. 3). Using the average value of the same eight vessels, the number of sightings decreased after 1200 (time of the maximum value); the rate of decrease remained within 60%, except at 1700. Five vessels showed the maximum value between 1200 and 1400, but for the *Hokko Maru* the maximum value was obtained at 1700, and for the *Shoyo Maru* the maximum value was obtained at 0600. These findings suggest that the number of sightings by time were related to many elements, and no clear trend by time was recognized. It is considered that there was no time of day at which it was extremely difficult to find marine debris.

Sighting Rate by Distance

In this survey, we usually observed at close range from the stern the distances and angles each debris items sighted. The distance at right angles to the track of the vessel (right angle distance) was measured, and marine debris was collected by category (Fig. 4). The number of sightings decreased as the right angle distance increased, and the number of sightings per 10 m accounted for <5% when the distance exceeded 100 m. Therefore, in estimating the number of sightings, the sighting width of 200 m, 100 m on each side of the track, was also estimated.

The relationship between right angle distance and the number of sightings of marine debris indicated a distribution with the maximum value of 10 to 20 m except for pieces of wood and drifting logs. Since the position of the marine debris never changed and never showed any movement against the vessel, it was easier to spot marine debris that was closer to the observers. If an observer could stop and scan the sea completely, the number of sightings would likely be in proportion to the distance. However, when sightings are conducted from a moving vessel it is not always possible to find marine debris close to the observer. As the vessel is sailing, the closer the debris is to the observer, the shorter the time in which it remains in the observer's visual field. Also it is not possible

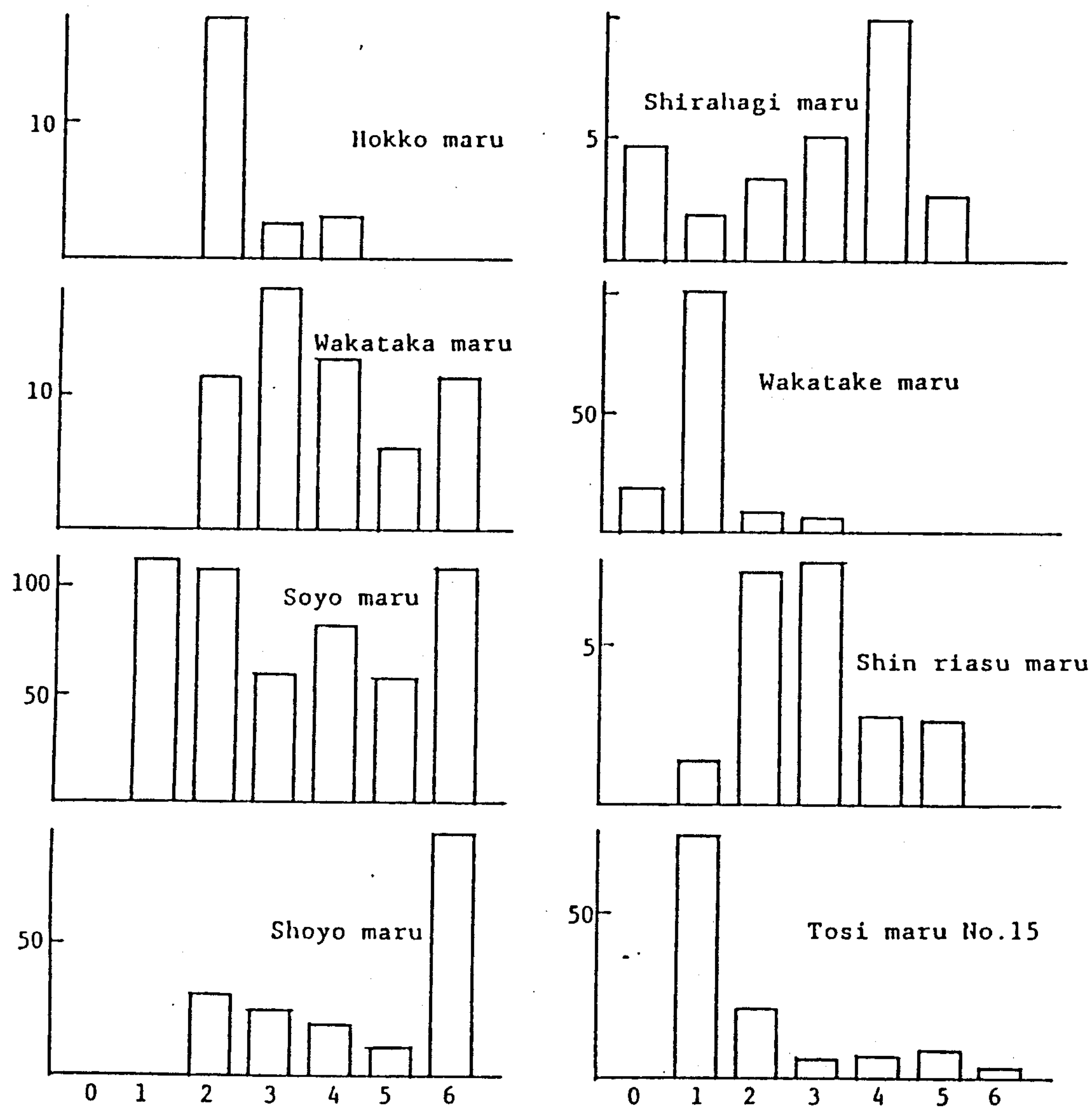


Figure 2.--Number of marine debris pieces sighted per 100 nmi in terms of wind force (Beaufort scale) for each vessel.

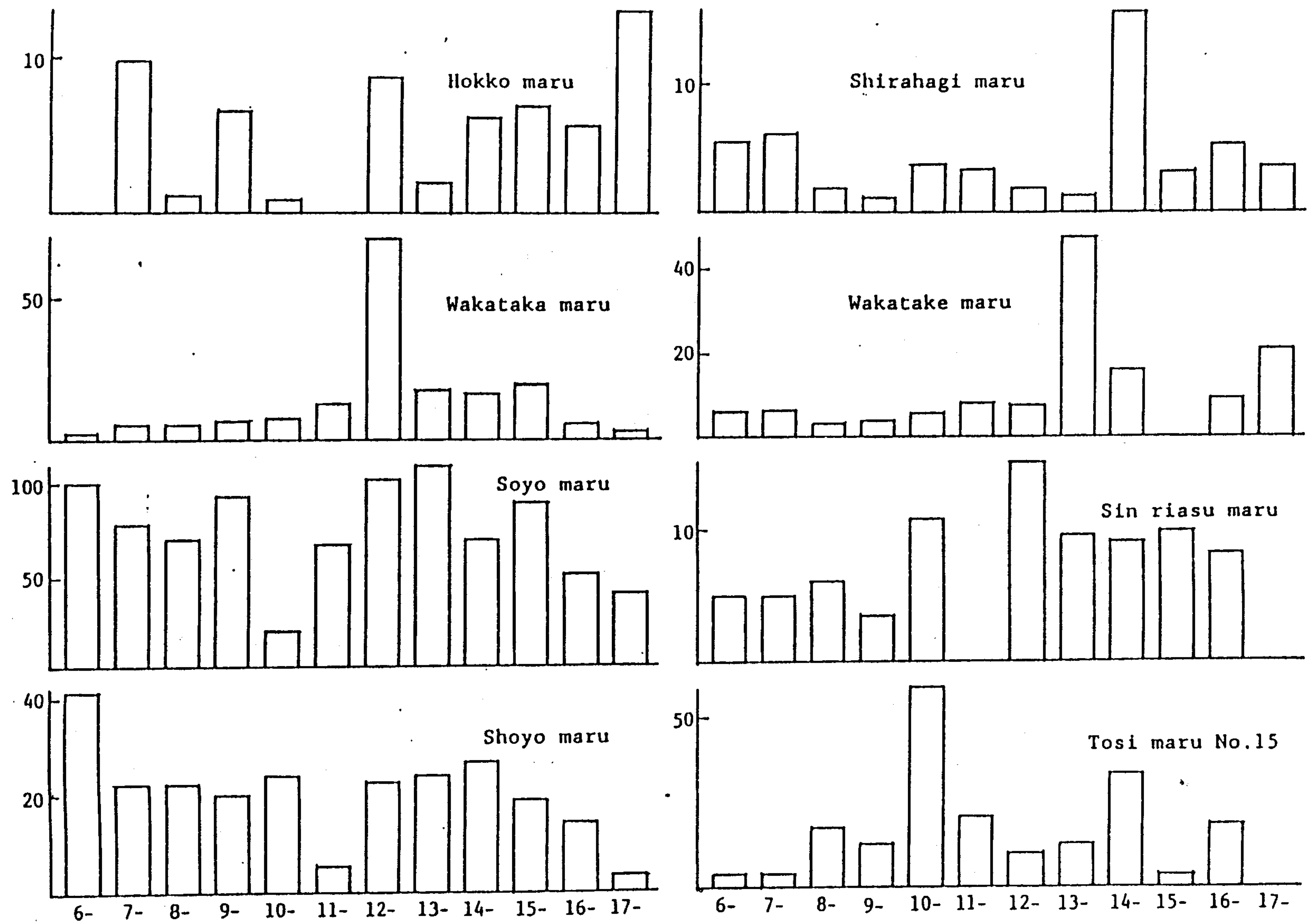


Figure 3.--Number of marine debris pieces sighted in terms of time of observation for each vessel.

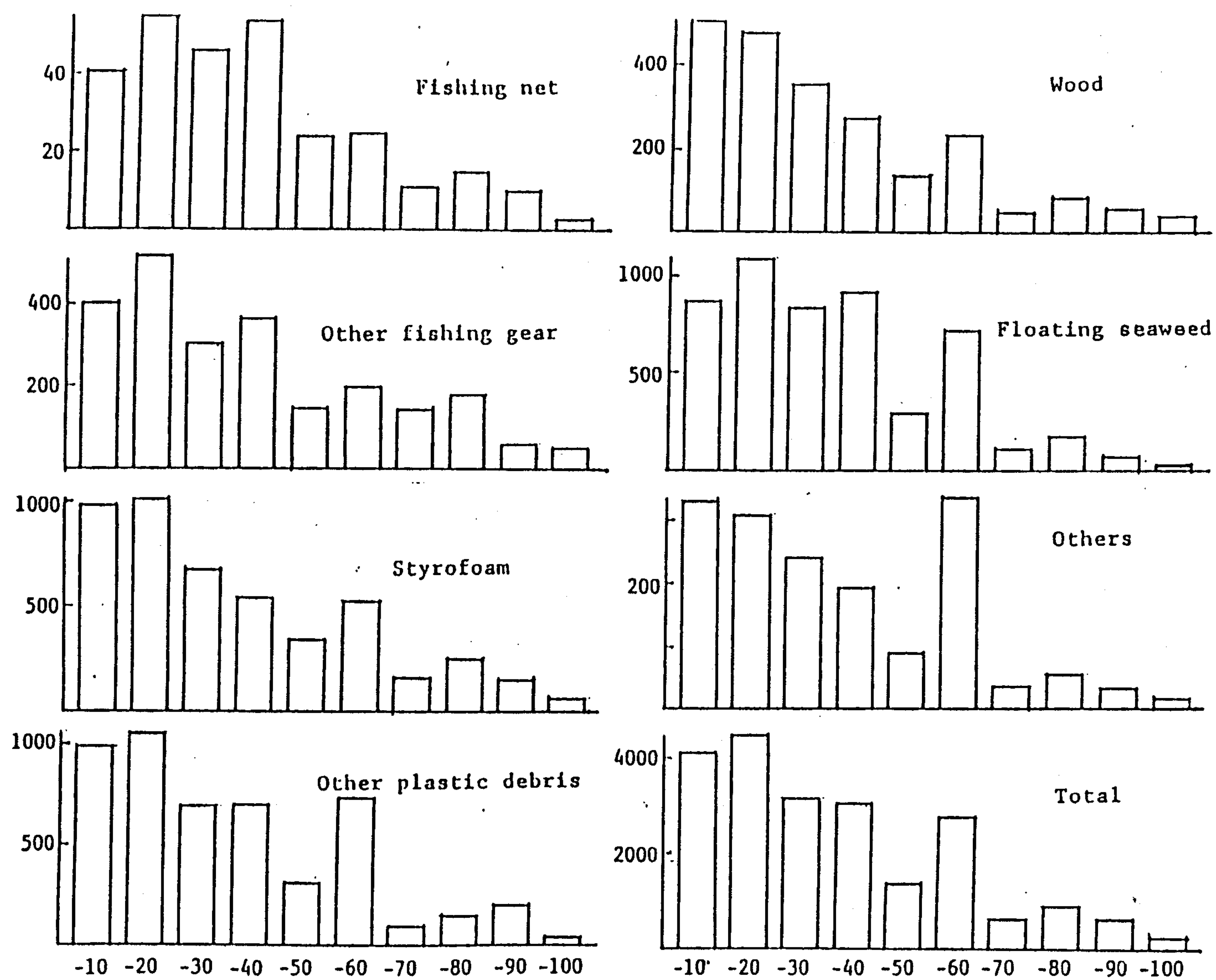


Figure 4.--Number of marine debris pieces sighted in terms of right angle distance (in meters) by type of debris.

to find marine debris on the sea when it is hidden behind the vessel. It is thought that there is a preferred distance for finding marine debris when the sighting is conducted from a fixed position. This was determined by the fact that in comparison with the sightings in Japanese waters and those in the Pacific Ocean, the number of sightings at a distance of 10 to 20 m tended to be larger than the number of sightings at a distance of 0 to 10 m.

Vessels conducting surveys in the Pacific Ocean were larger in size and had higher speeds than vessels conducting surveys in Japanese waters only. For the above two reasons, it is considered to be more difficult to observe the surface of the sea that is closer to the vessel. In addition, a decrease in the number of sightings in the range of 0 to 10 m was also caused by errors which arose from rounding to the nearest whole number when the angles sighted were reported. That is, as an angle was measured with the eye, the article which was recognized in the range of 0° to 5° was mostly reported as at 5°. If a distance sighted exceeded 115 m, marine debris was located from 10 to 20 m in right angle distance. For the optimum distance sighted in the relationship between right angle distance and number of sightings, it is necessary to collect more data and to continue further studies. In this report, the effective width was calculated from the assumption that the sighting probability on the path is 1.

Distribution Density of Marine Debris

Relationship between right angle distance (Y) and sighting rate (g(Y)) is shown in the following curvilinear equation:

$$g(Y) = 1 - \mathrm{Exp}\,(-(Y/A)\hat{}(1-B)).$$

The coefficients of each type of marine debris are shown in Table 3.

The number of individual items per unit area for each type of marine debris was calculated by blocks (5° of latitude by 10° of longitude) on the basis of the following equation (Seber 1982):

$$N = \frac{nf(0)}{2L}.$$

N = Number of individuals per unit area.
n = Number sighted.
L = Steaming distance.
f(0) = 1/effective width.

Figure 5 shows the number of individual items per unit area by block obtained in this manner, and by the type of marine debris.

Table 3.--Coefficients of each type of marine debris.

Type of marine debris	A	B	f(0)
Fishing net	46,099	4,178	0.01752
Other fishing gear	39,623	3,627	0.01923
Styrofoam	41,598	3,969	0.01891
Other petrochemical products	46,366	4,613	0.01779
Pieces of wood and drifting logs	38,330	4,165	0.02060
Floating seaweed	47,890	5,679	0.01797
Other	31,485	3,565	0.02331
Total debris	38,162	3,430	0.01951

DISCUSSION

Distribution of Effort

A glance at the distribution of effort by block tells its own story: The blocks where effort was expended abundantly were concentrated in Japanese waters (Fig. 6). There were three blocks in which the survey distance exceeded 10,000 nmi, and the blocks which exceeded 3,000 nmi were also restricted to Japanese waters and adjacent areas. Next to the Japanese waters and adjacent areas, the offshore area of California, the southern area of the Alaska Peninsula, and the Northwestern Hawaiian Islands were also areas in which a large amount of effort was expended. However, the former two areas were also completely surveyed, one by the *Kaiyo Maru* only and the other by the *Toko Maru* and the *Shin Riasu Maru*, respectively, and the survey season was biased. As the Northwestern Hawaiian Islands are in the path of vessels which come and go from Honolulu, the area of survey is restricted.

Furthermore, glancing at numbers sighted by block, even blocks of other plastic debris, which has the most abundant sightings, the blocks in which 50 or more petrochemical items were found were only 18.4% of the total number of blocks in which petrochemicals were found. In order to obtain reliable density of marine debris, ideally speaking, it is necessary to conduct surveys evenly throughout the blocks in each season. As we mentioned before, in the present surveys, effort is frequently biased by season and by block, and the number of reliable blocks are extremely few. However, we calculated tentative density using the results of sightings as they were obtained.

Distribution of Marine Debris by Type

There were only 310 individual sightings of fishing nets, and reliable results were not obtained. However, the blocks in which sighting density was high were from lat. 25° to 40°N and long. 170° to 130°W, and in that area the density increased toward the east. Sighting density was next highest in Japanese waters and the East China Sea, but was only 2% of the block in which the density was the highest. In waters of lat. 45° to 50°N,

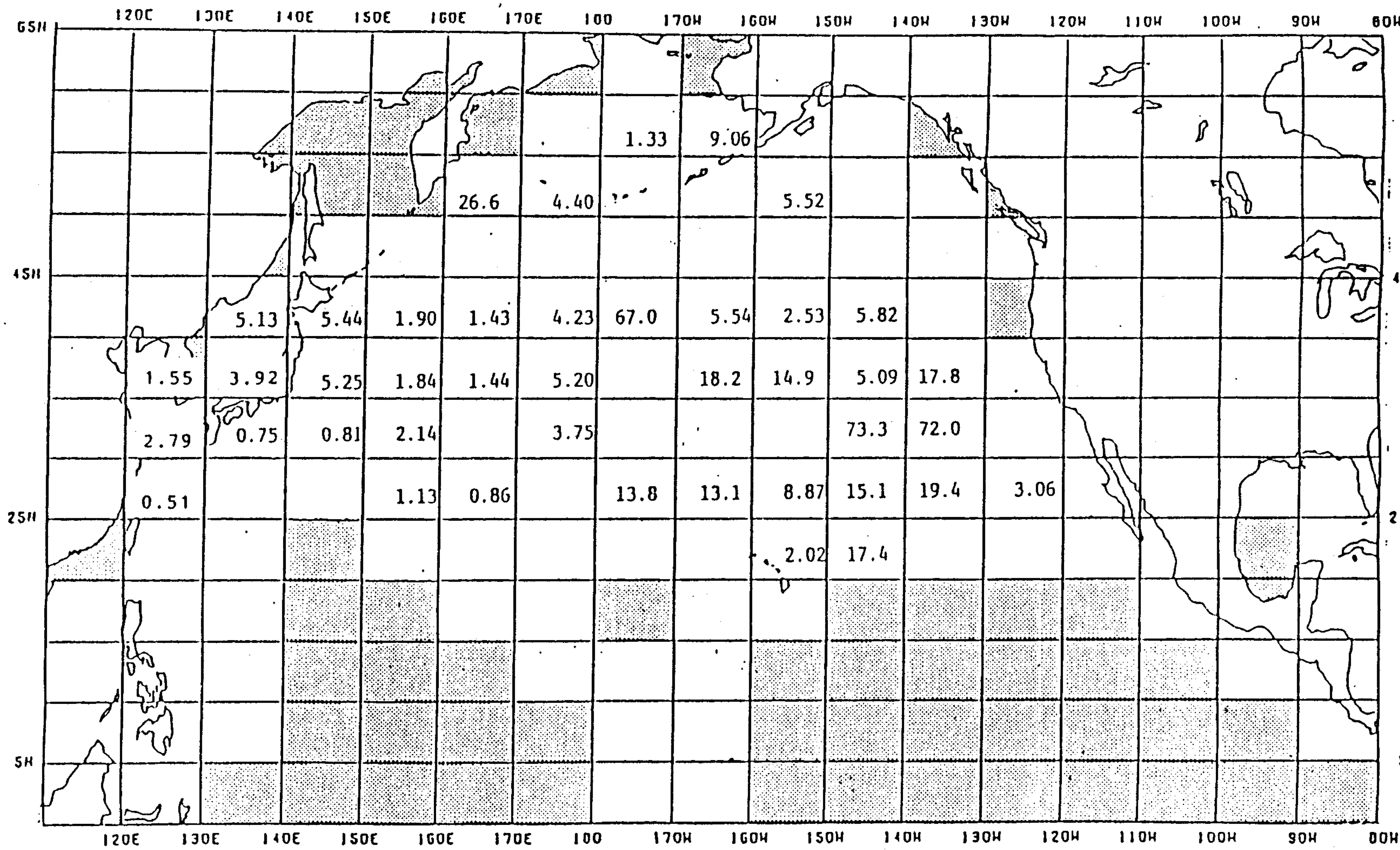


Figure 5A.--Estimated density distribution of fishing net debris in 1987.
Unit: number of debris pieces $\times 10^{-1}$ per 1 nmi^2.

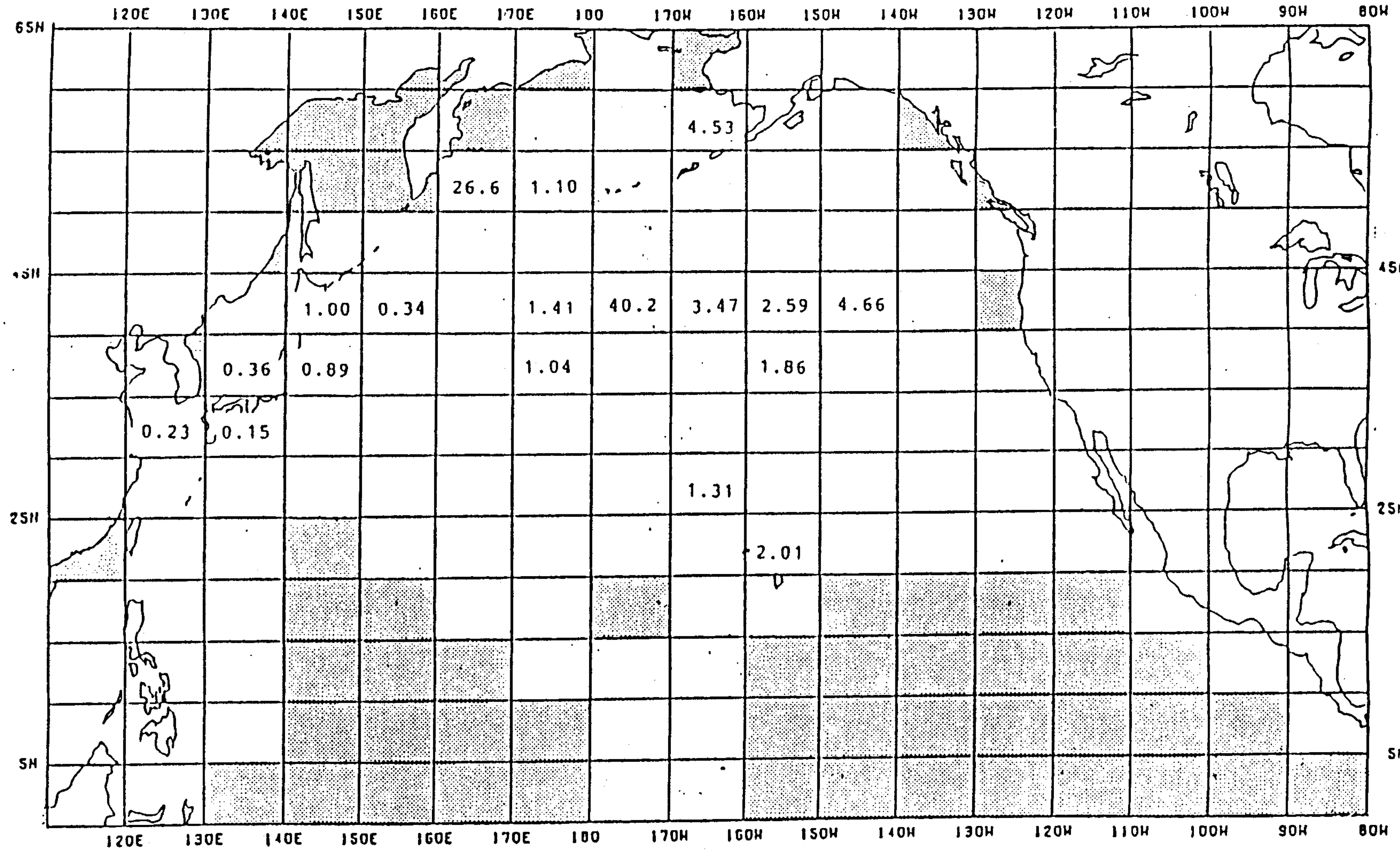


Figure 5B.--Estimated density distribution of trawl net debris in 1987.
Unit: number of debris pieces × 10^{-1} per 1 nmi^2.

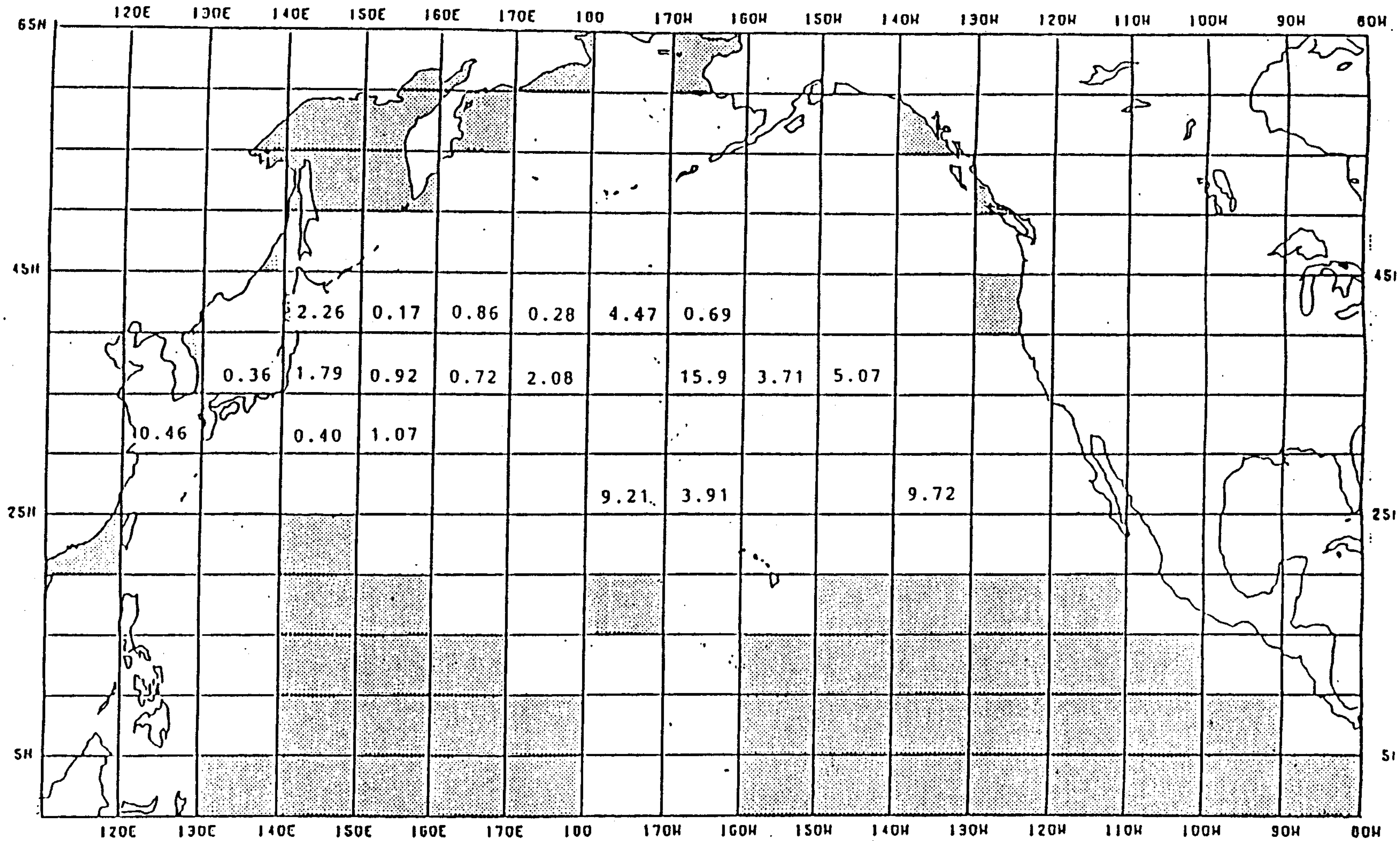


Figure 5C.--Estimated density distribution of drift net debris in 1987.
Unit: number of debris pieces $\times 10^{-1}$ per 1 nmi^2.

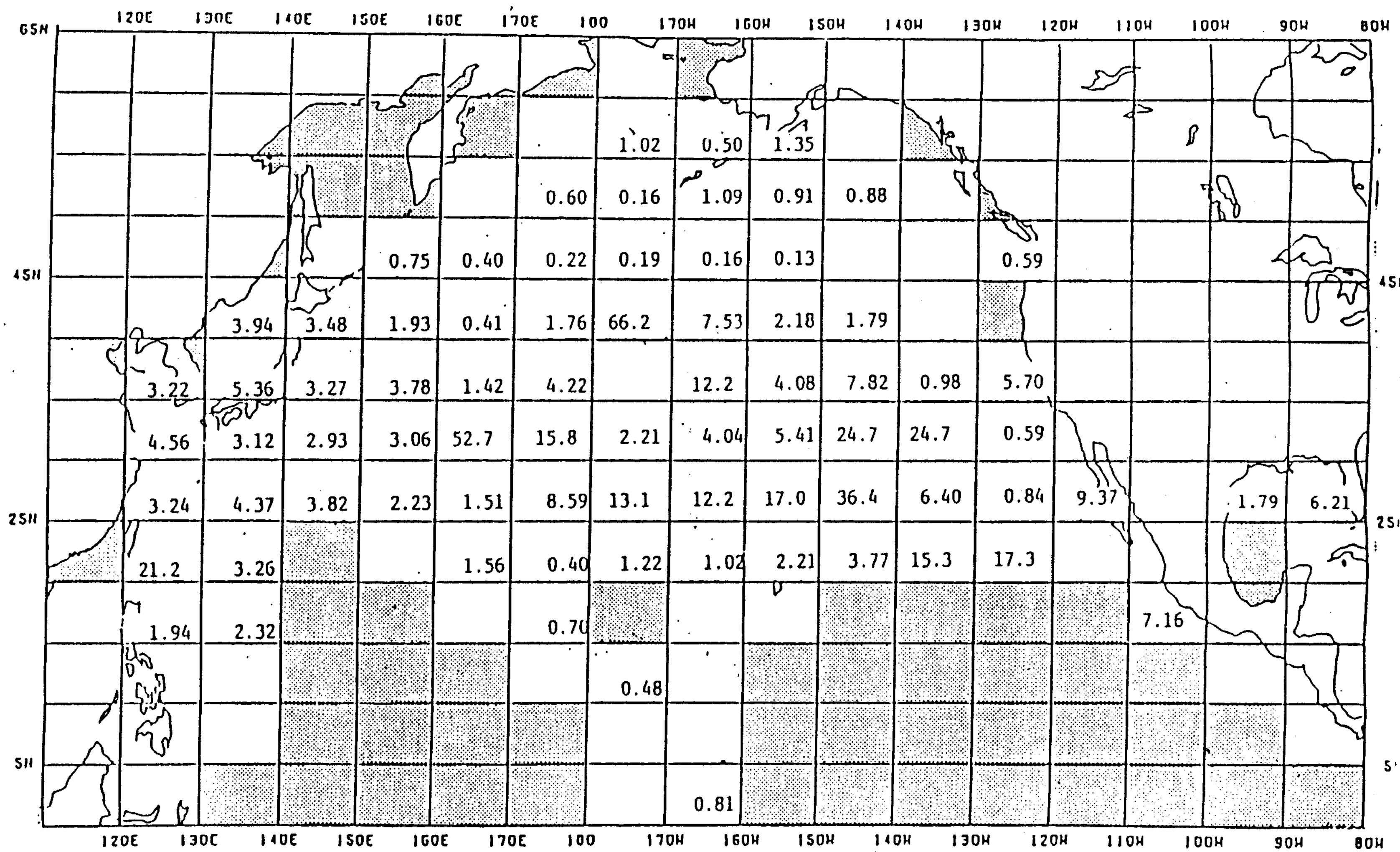


Figure 5D.--Estimated density distribution of other fishing gear debris in 1987. Unit: number of debris pieces $\times 10^{-1}$ per 1 nmi^2.

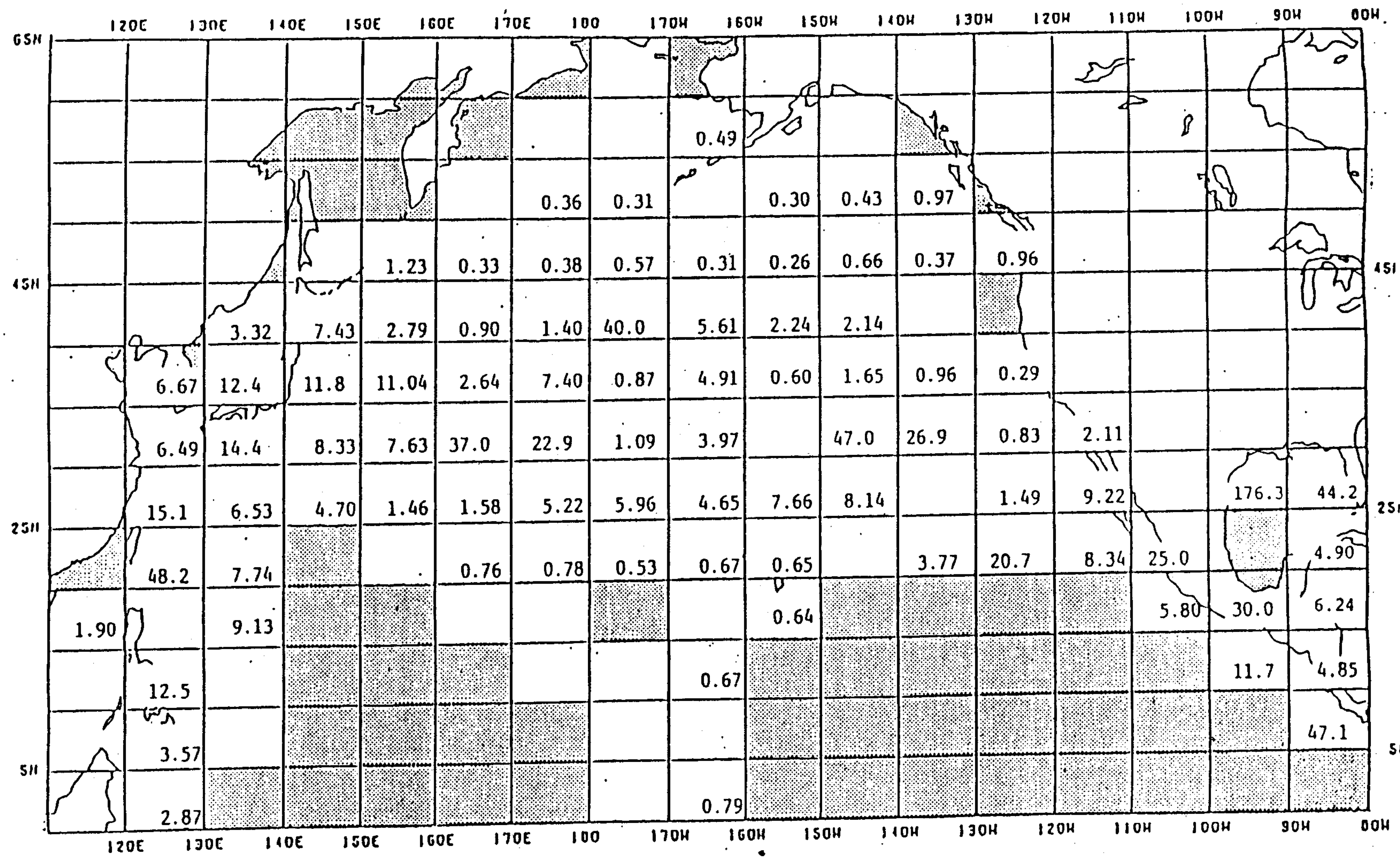


Figure 5E.--Estimated density distribution of Styrofoam debris in 1987.
Unit: number of debris pieces × 10^{-1} per 1 nmi^2.

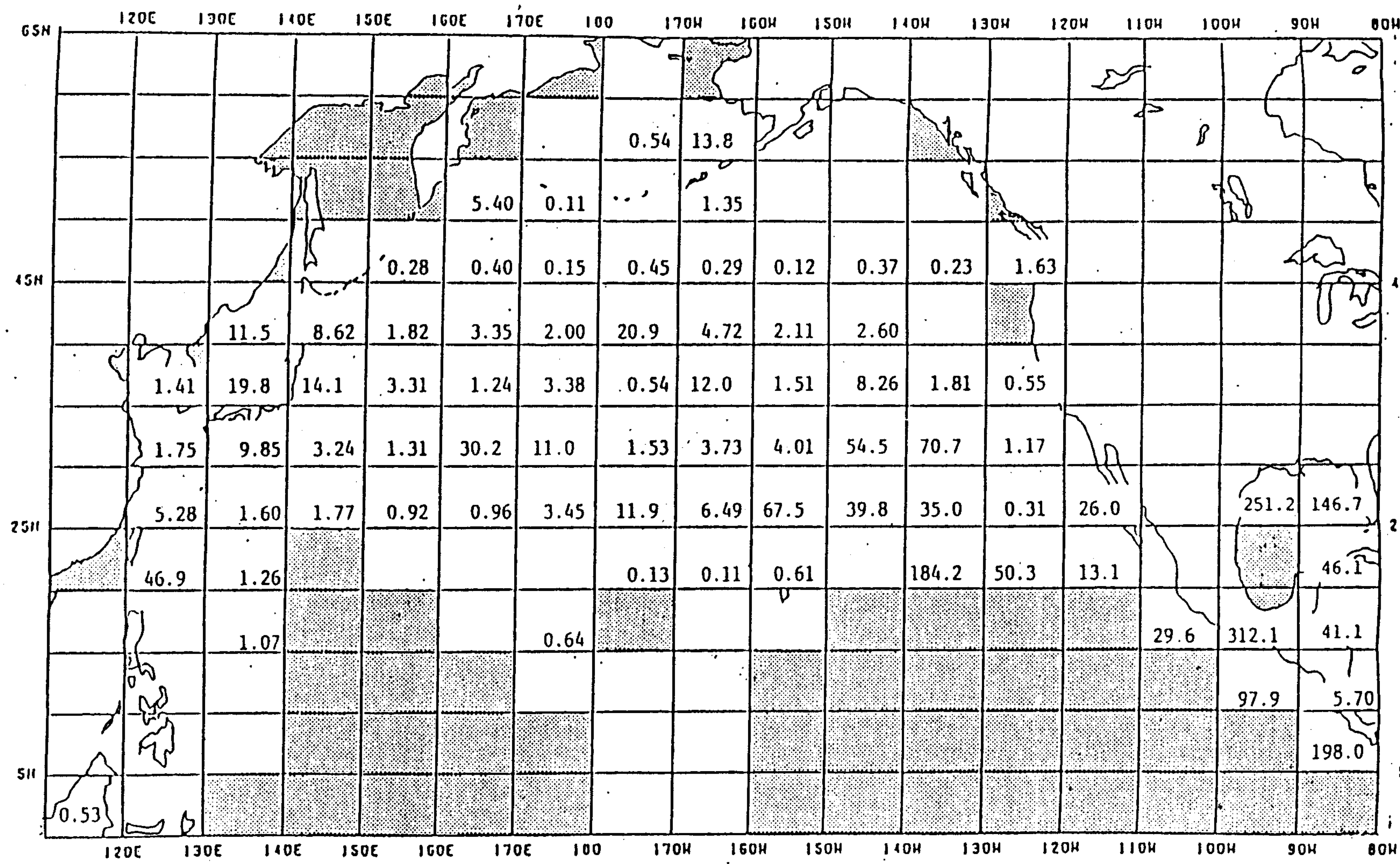


Figure 5F.--Estimated density distribution of other plastic debris in 1987.
Unit: number of debris pieces $\times 10^{-1}$ per 1 nmi^2.

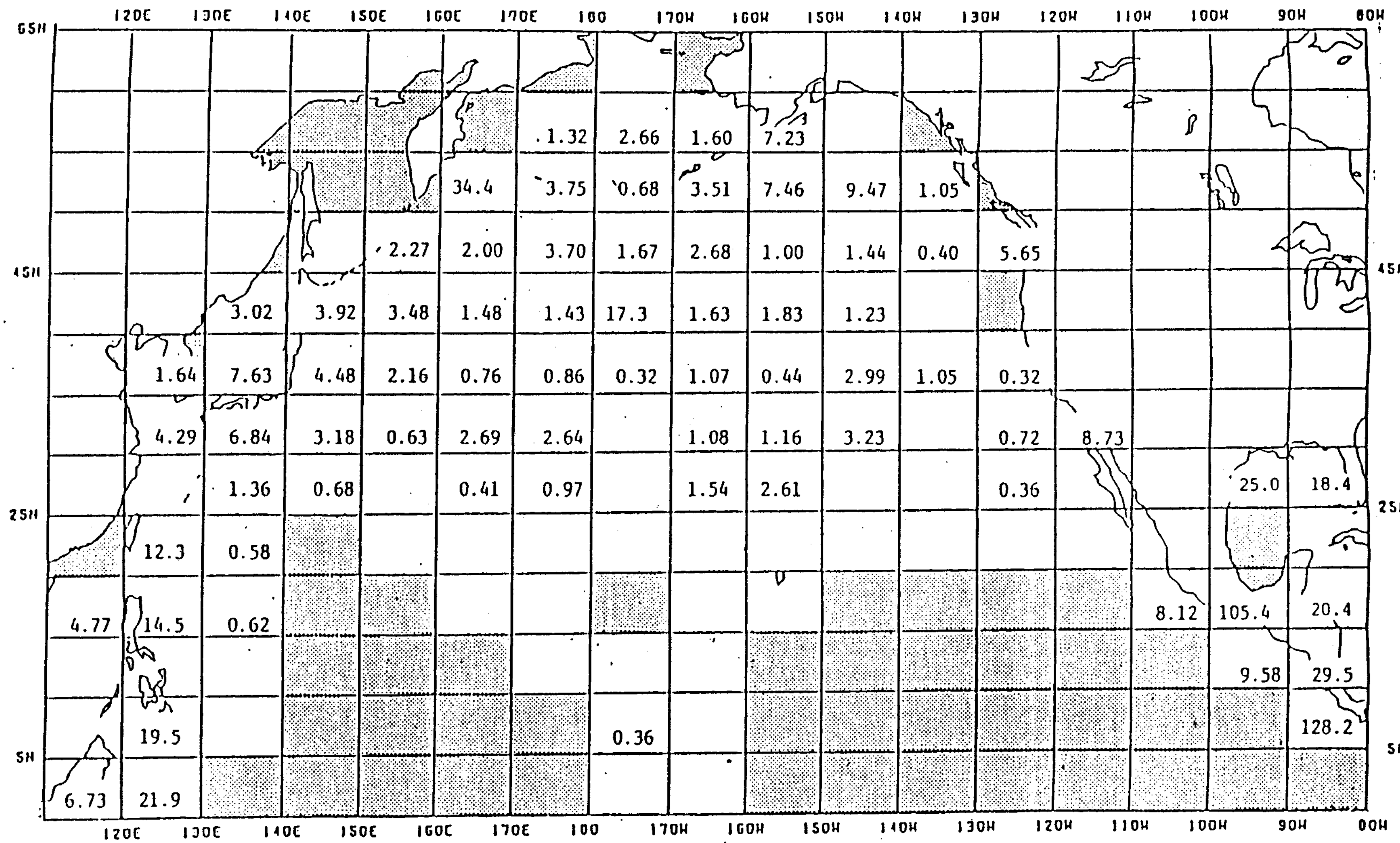


Figure 5G.--Estimated density distribution of wood debris in 1987.
Unit: number of debris pieces $\times 10^{-1}$ per 1 nmi^2.

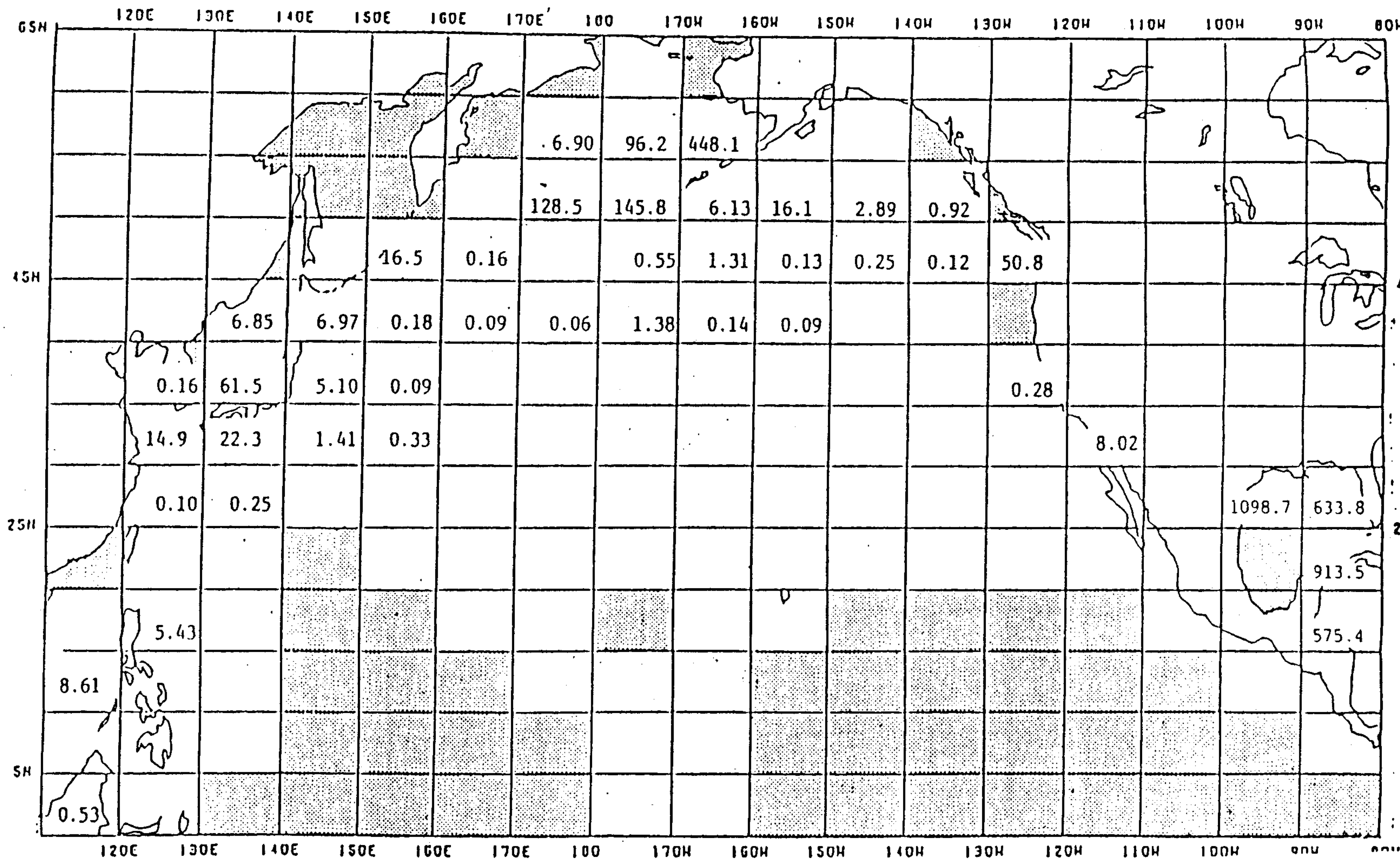


Figure 5H.--Estimated density distribution of floating seaweed debris in 1987.
Unit: number of debris pieces $\times 10^{-1}$ per 1 nmi^2.

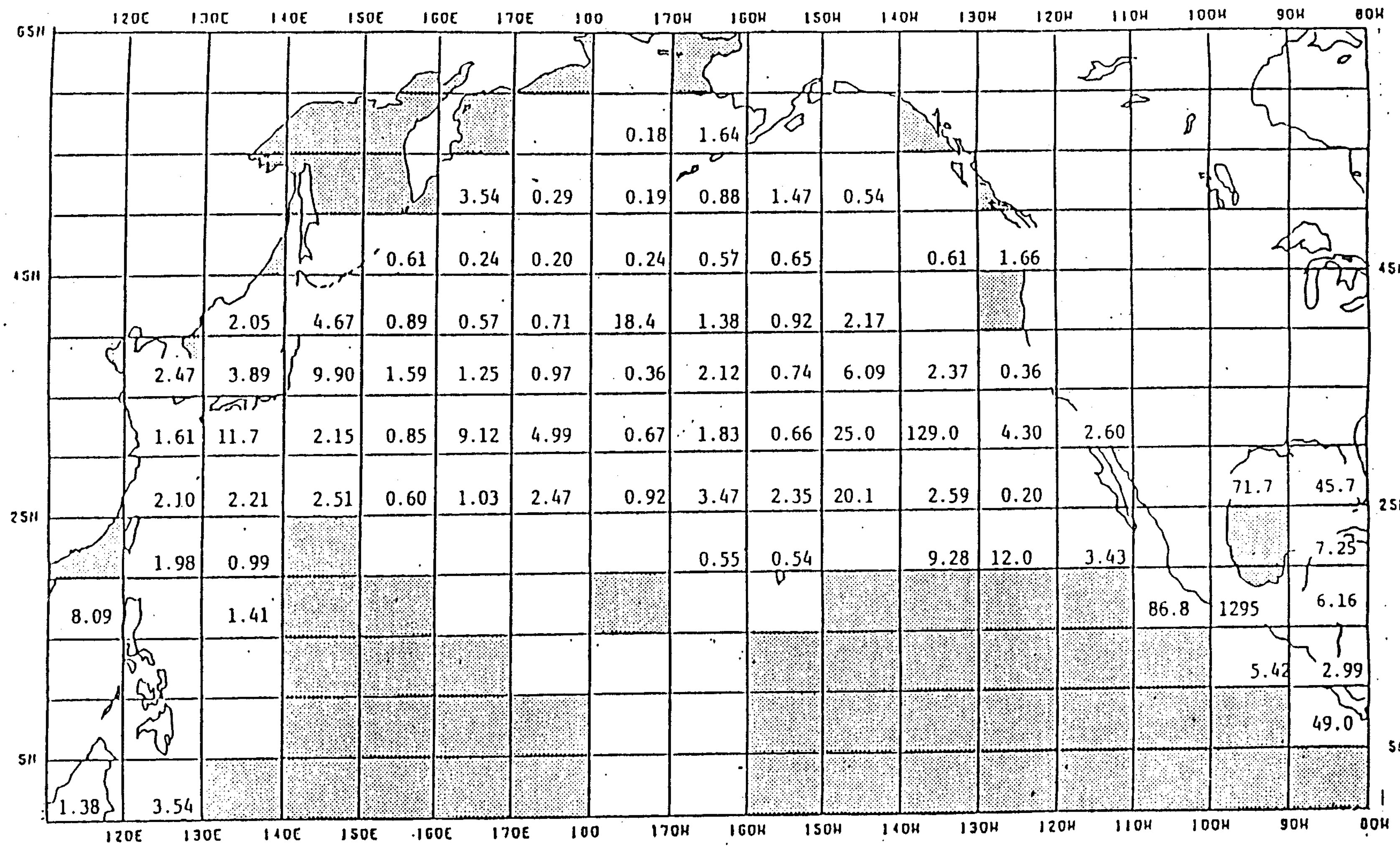


Figure 5I.--Estimated density distribution of other marine debris in 1987.
Unit: number of debris pieces $\times 10^{-1}$ per 1 nmi^2.

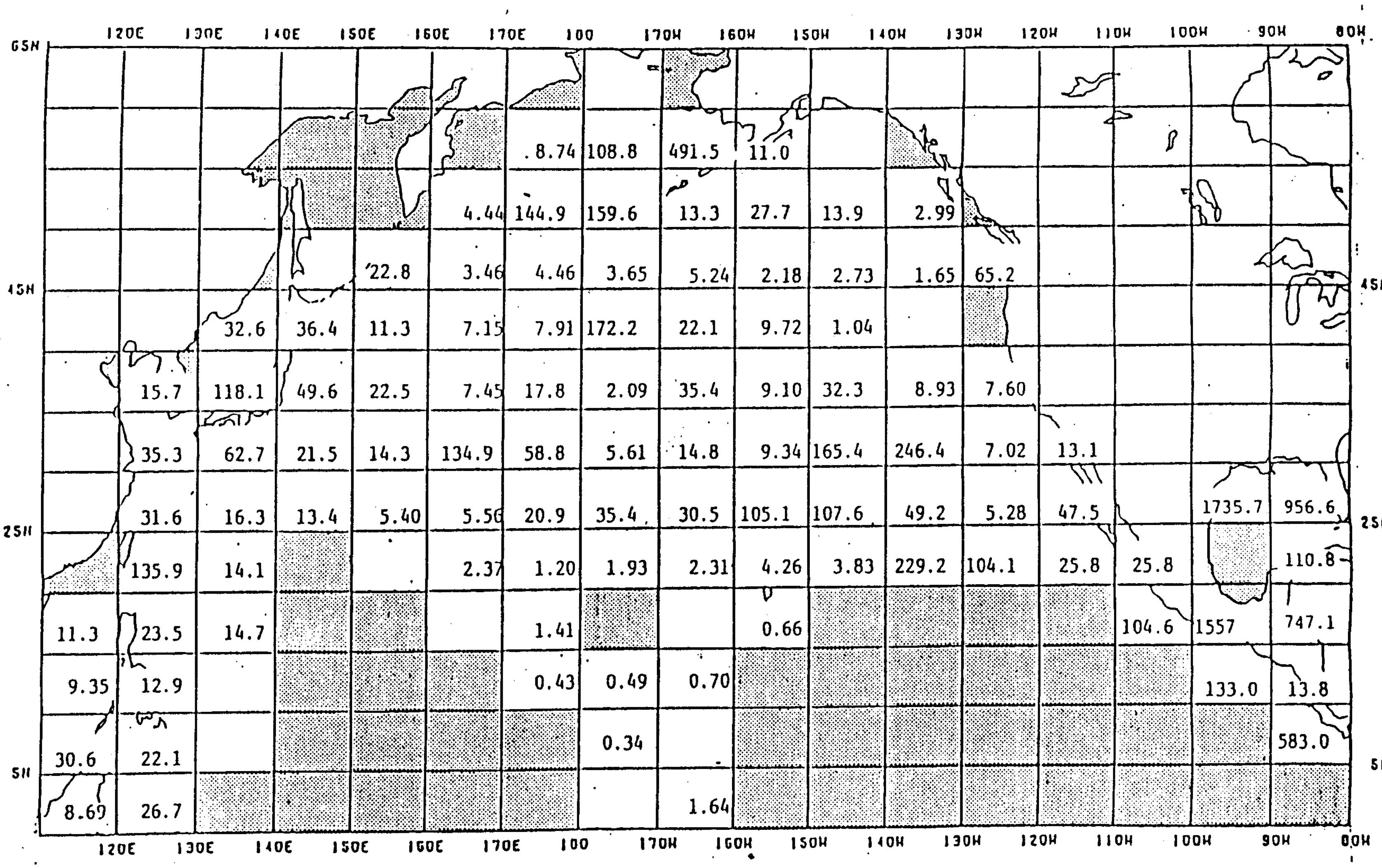


Figure 5J.--Estimated density distribution of total marine debris in 1987.
Unit: number of debris pieces $\times 10^{-1}$ per 1 nmi^2.

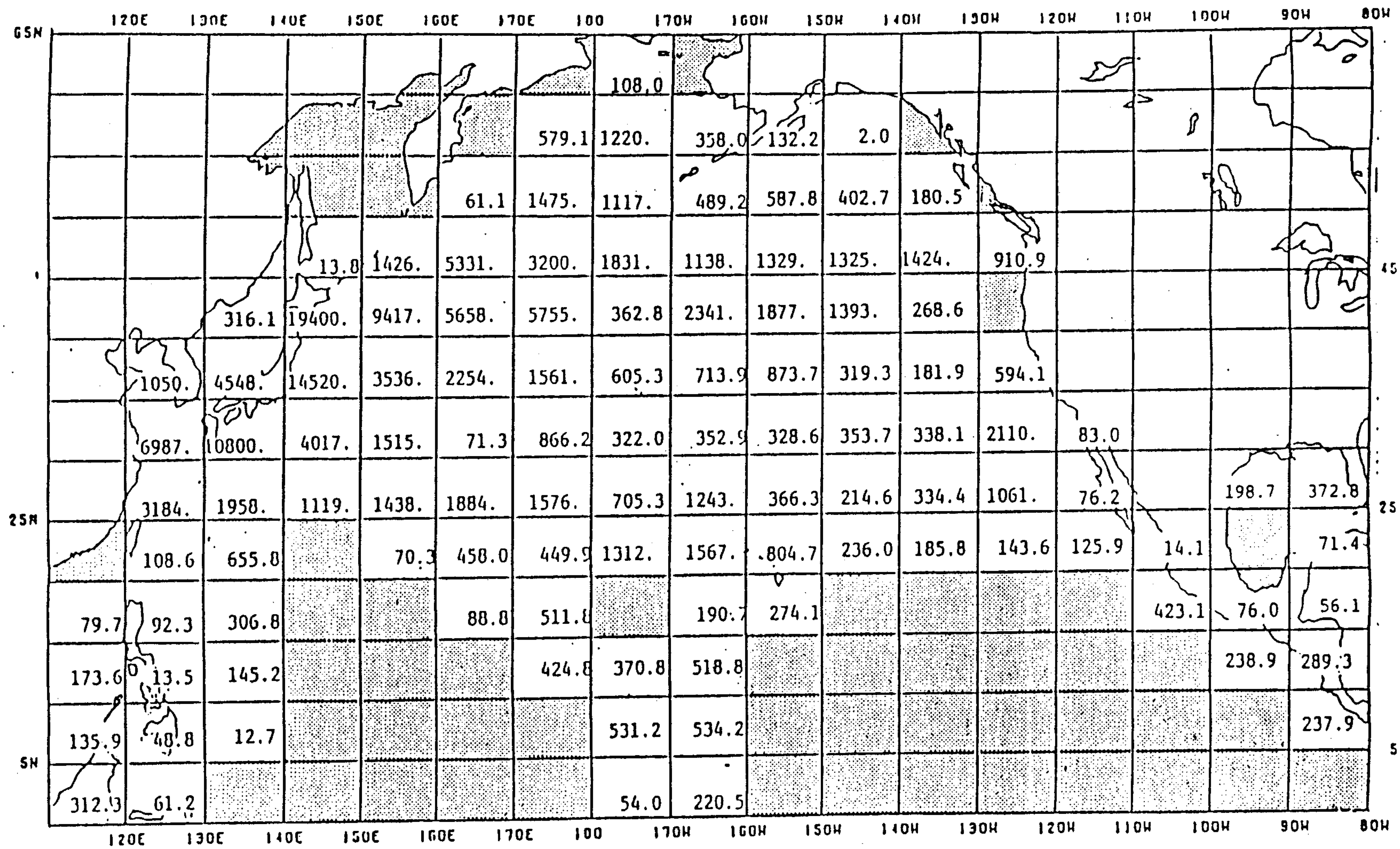


Figure 6.--Surveyed cruising distance in each 5° × 10° area in 1987. Unit: nautical mile.

fishing nets were not found at all. The distribution split to both south and north with this area in between, and it was thought that fishing nets found in the south were transported by currents moving from west to east. There were many unidentified fishing nets, and characteristics by kind of fishing net were not clearly recognizable. In waters north of lat. 50°N, only trawl nets were identified.

The numbers of other fishing gear sighted were greater than the number of fishing nets, and other fishing gear was found in 70.1% of all the areas surveyed. Although a distribution pattern of other fishing gear was similar to that of fishing nets, the blocks in which density was high inclined toward the south.

A great number of Styrofoam pieces were sighted. The range of distribution was widest, Styrofoam items being found in 77.8% of the blocks in the area surveyed. The distribution pattern was different for petrochemical articles other than Styrofoam, and the areas in which density was high were found in waters off Japan, at lat. 25° to 35°N and long. 170°W, lat. 25° to 35°N and long. 160°E to 140°W, in the Gulf of Mexico, and in the coastal areas of Central America. Areas which showed a comparatively high density were scattered widely. To explain the difference in this distribution pattern, petrochemical articles except Styrofoam are transported mainly by ocean currents, while Styrofoam items are floating on the surface of the sea and are thought to be strongly influenced by wind.

Other plastic debris was sighted in the greatest numbers (8,544 items), and the number of blocks sighted was the same as for other fishing gears. The distribution pattern was also similar. Six blocks in which the density was highest were concentrated in the range of lat. 20° to 35°N and long. 160°E to 130°W, followed by blocks in Japanese waters. In addition, an area in which the density was extremely high was in the Gulf of Mexico as well as the coastal areas of Central America.

For pieces of wood and drifting logs, densities were high in the coastal areas, suggesting that pieces of wood and drifting logs come primarily from the rivers and coastal areas. Floating seaweed showed this trend remarkably, and beyond three coastal blocks it was not found at all.

Blocks of highest density of combined petrochemical articles were seen in the coastal areas of Central America, followed by blocks of high density concentrated in waters of lat. 20° to 35°N and long. 150° to 130°W. Although the number of blocks was small, there were also those that showed high density in waters of lat. 25° to 35°N and long. 170°E to 170°W. Furthermore, densities of marine debris that were <2% of the highest density block, could be found in Japanese waters and the East China Sea, but a considerably high density was shown in the wide range. As another distinctive phenomenon, density was low in any blocks in waters of lat. 45° to 50°N, and the North Pacific Ocean and the Bering Sea are separated by this area. It is believed that marine debris seldom passes from one of these areas to the other.

Figures used in the above determinations were the numbers of individual items sighted. When considering the effects of marine debris,

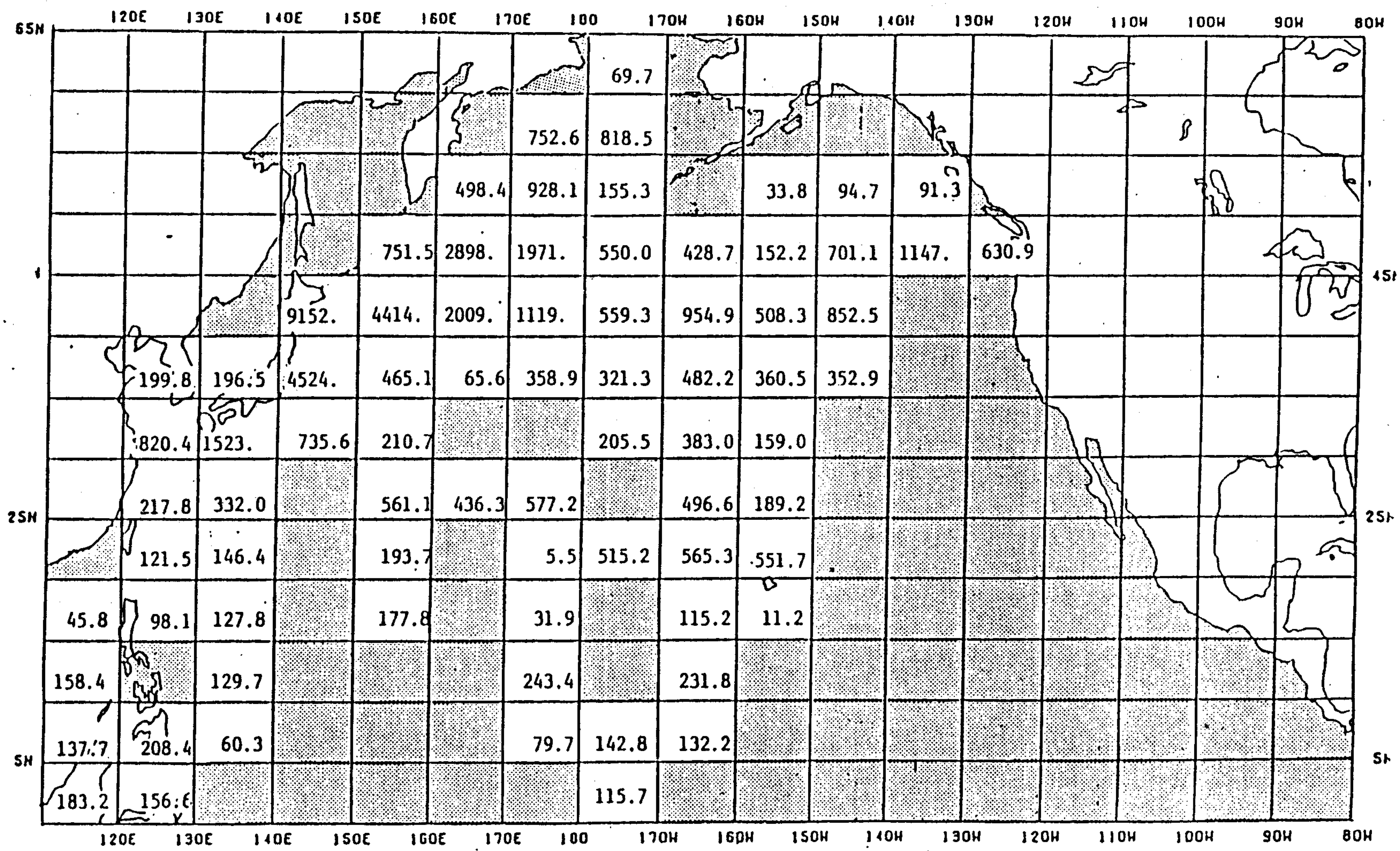


Figure 7.--Surveyed cruising distance in each 5° × 10° area in 1986. Unit: nautical mile.

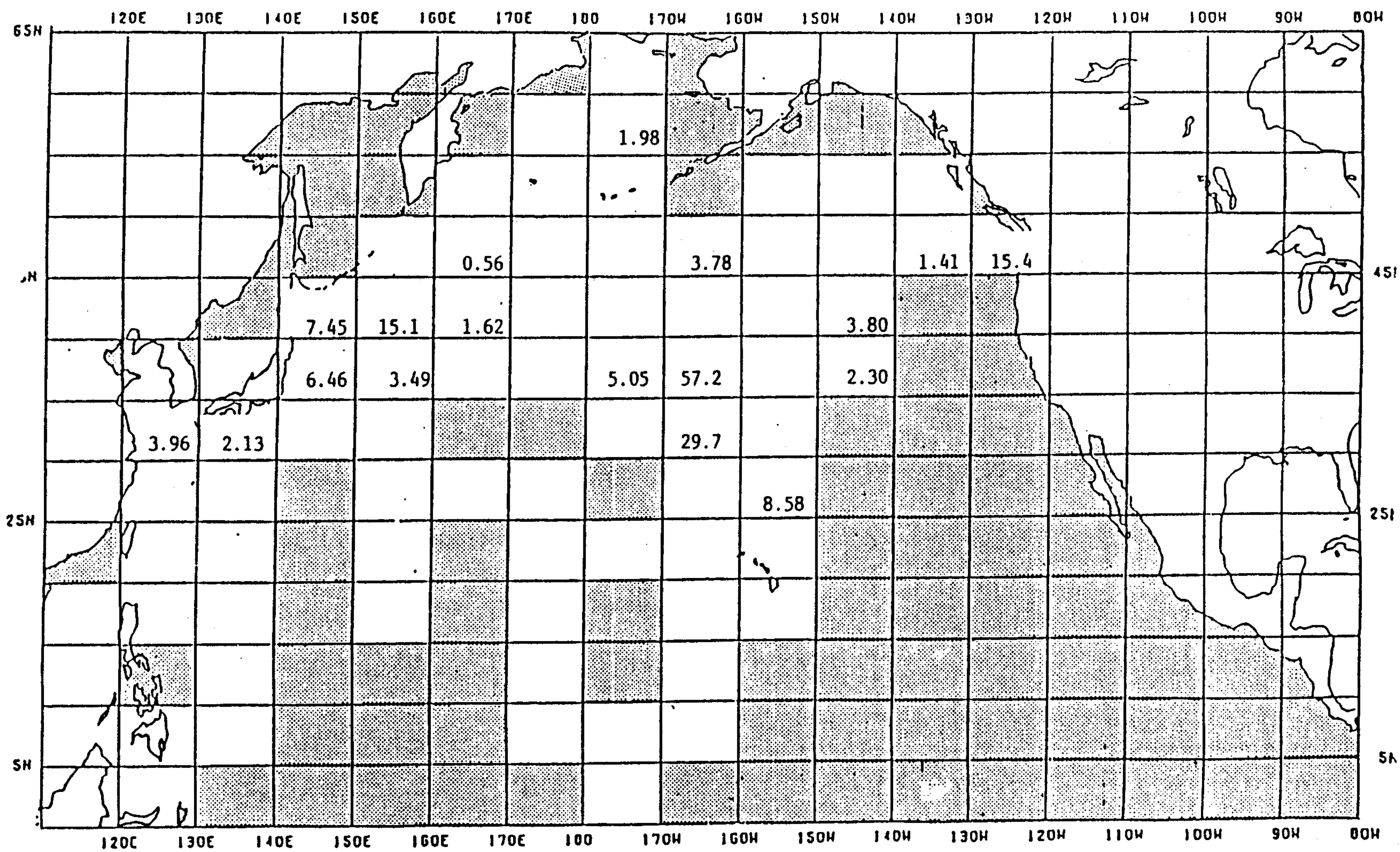


Figure 8A.--Estimated density distribution of fishing net debris in 1986.
Unit: number of debris pieces × 10^{-1} per 1 nmi^2.

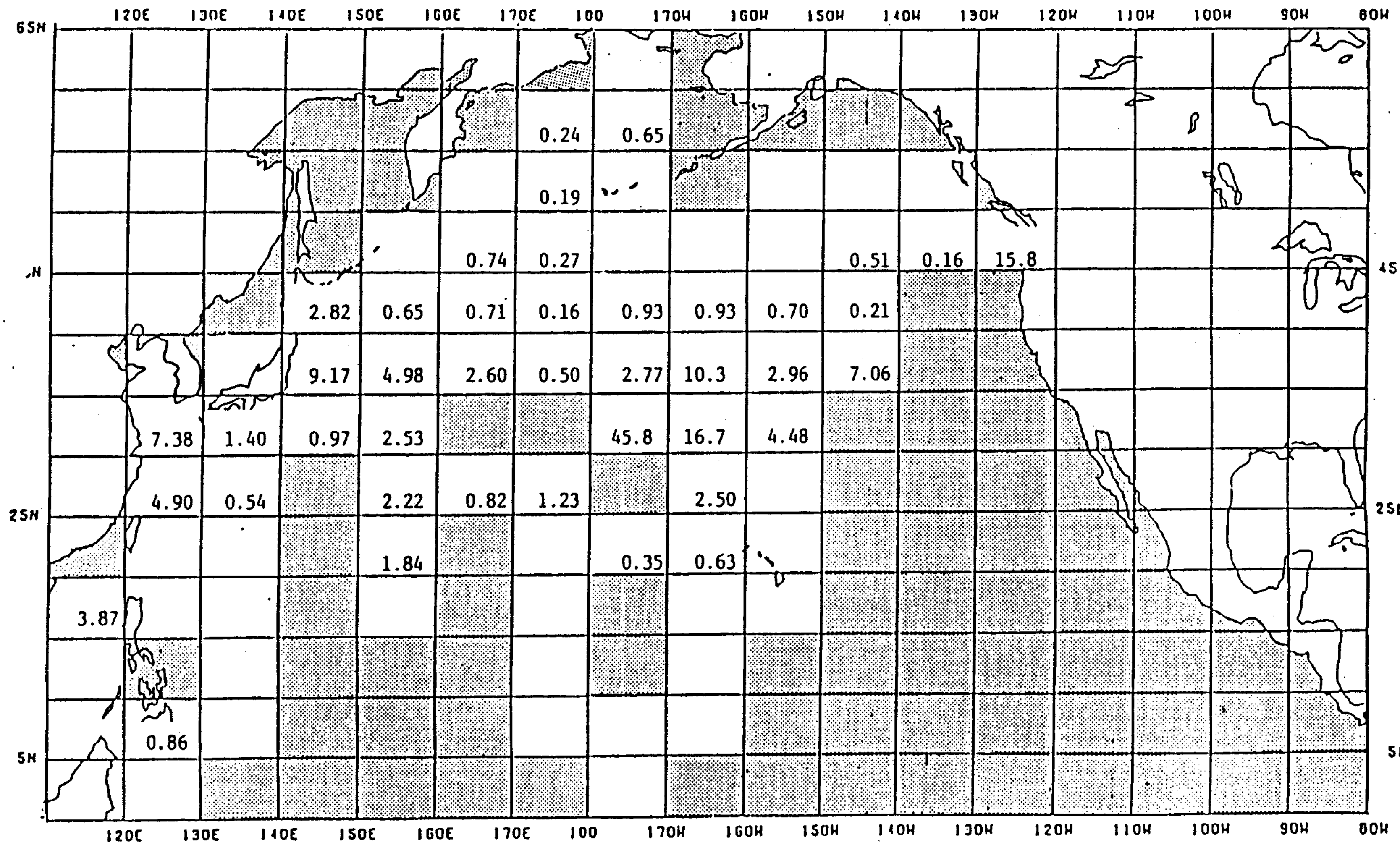


Figure 8B.--Estimated density distribution of other fishing gear debris in 1986.
Unit: number of debris pieces × 10^{-1} per 1 nmi^2.

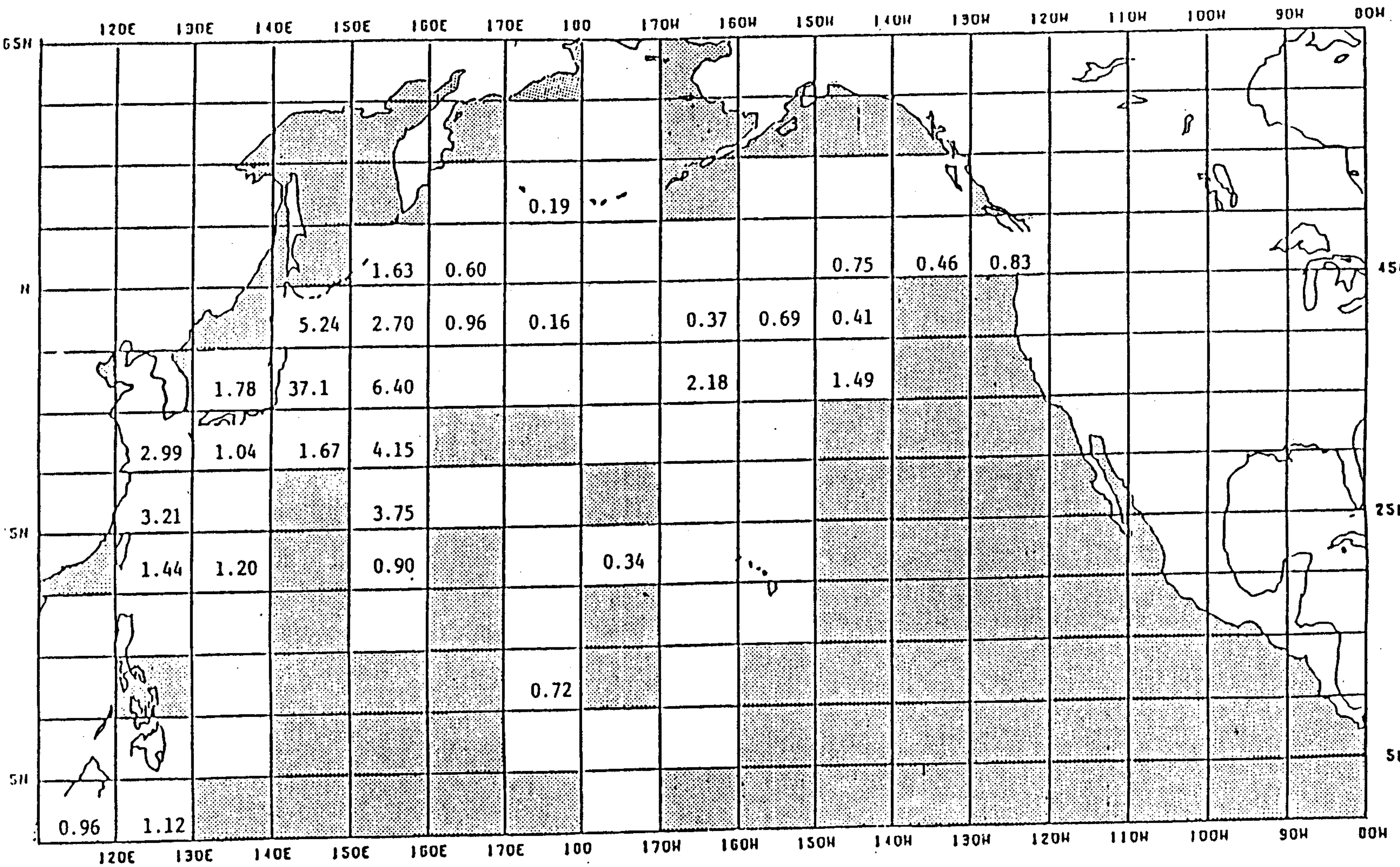


Figure 8C.--Estimated density distribution of Styrofoam debris in 1986.
Unit: number of debris pieces $\times 10^{-1}$ per 1 nmi^2.

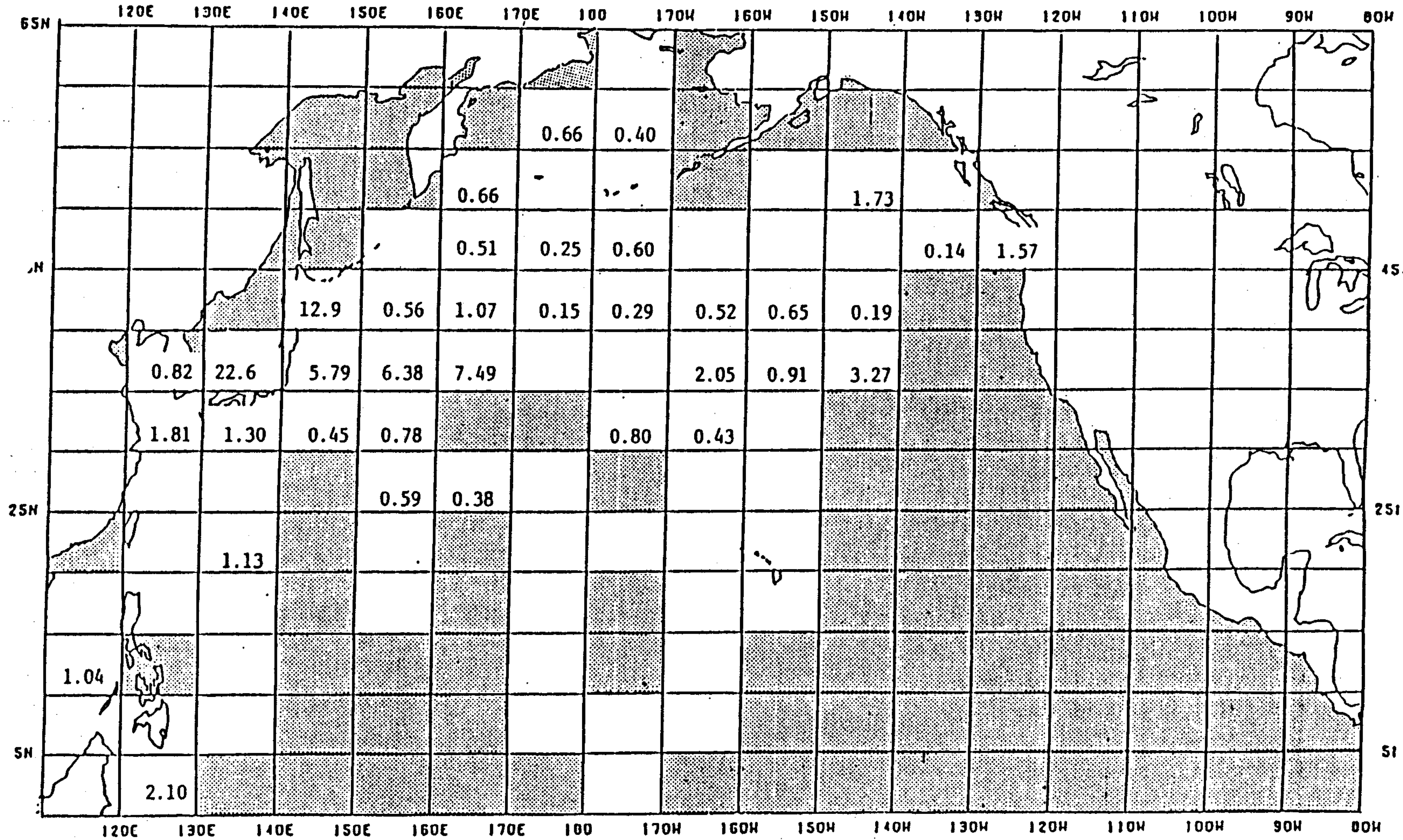


Figure 8D.--Estimated density distribution of other plastic debris in 1986.
Unit: number of debris pieces $\times 10^{-1}$ per 1 nmi^2.

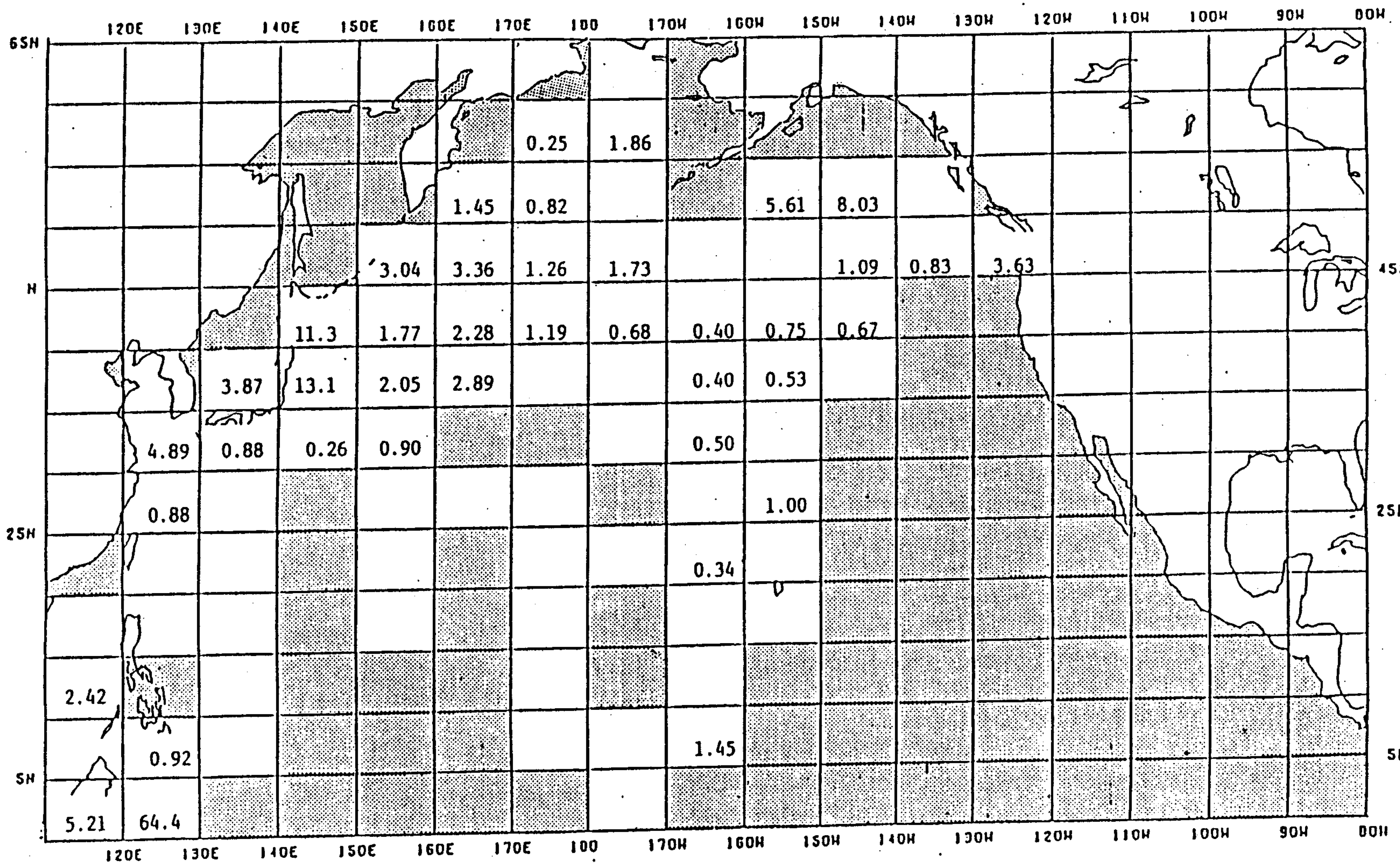


Figure 8E.--Estimated density distribution of wood debris in 1986.
Unit: number of debris pieces × 10^{-1} per 1 nmi^2.

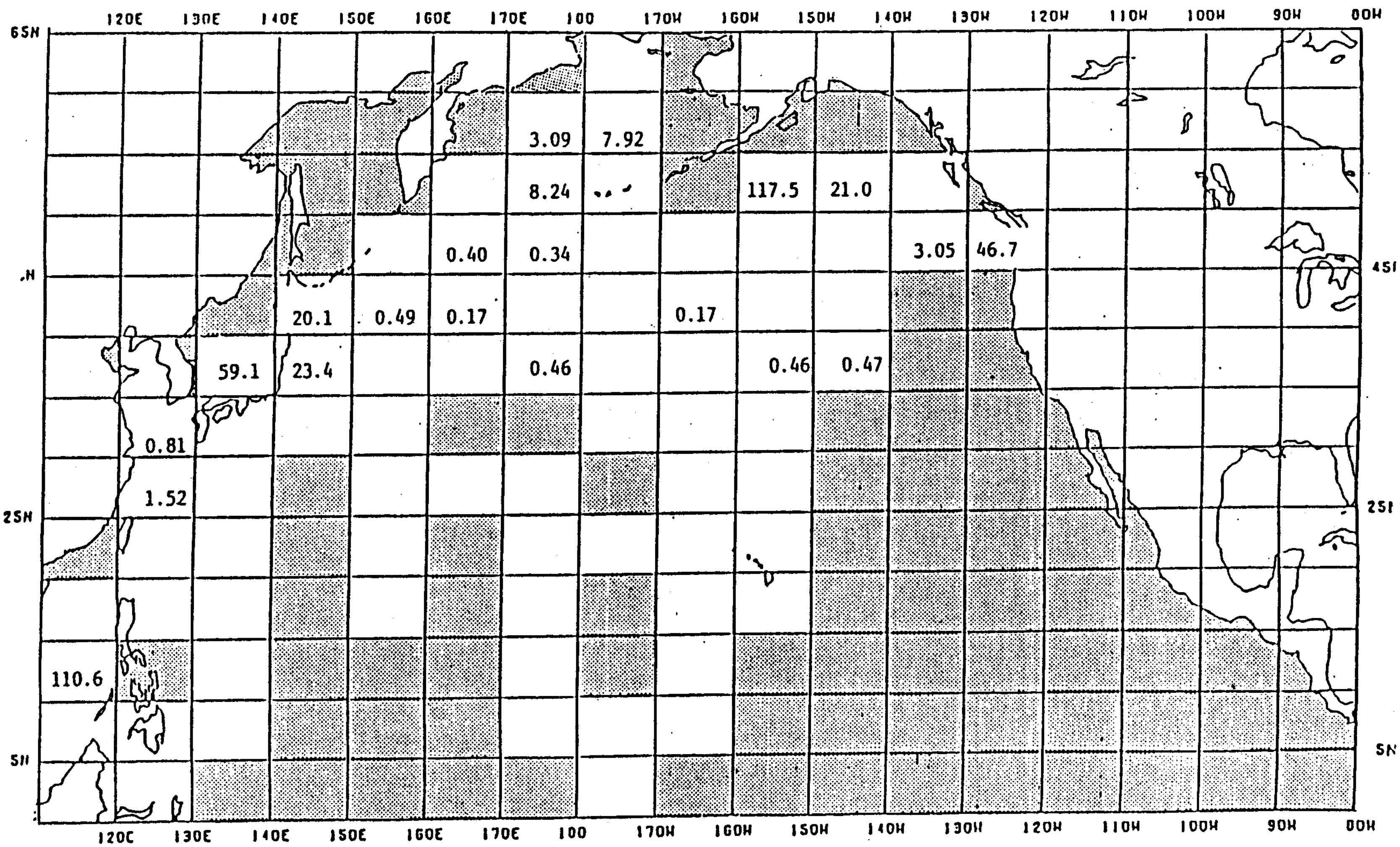


Figure 8F.--Estimated density distribution of floating seaweed debris in 1986.
Unit: number of debris pieces × 10^{-1} per 1 nmi^2.

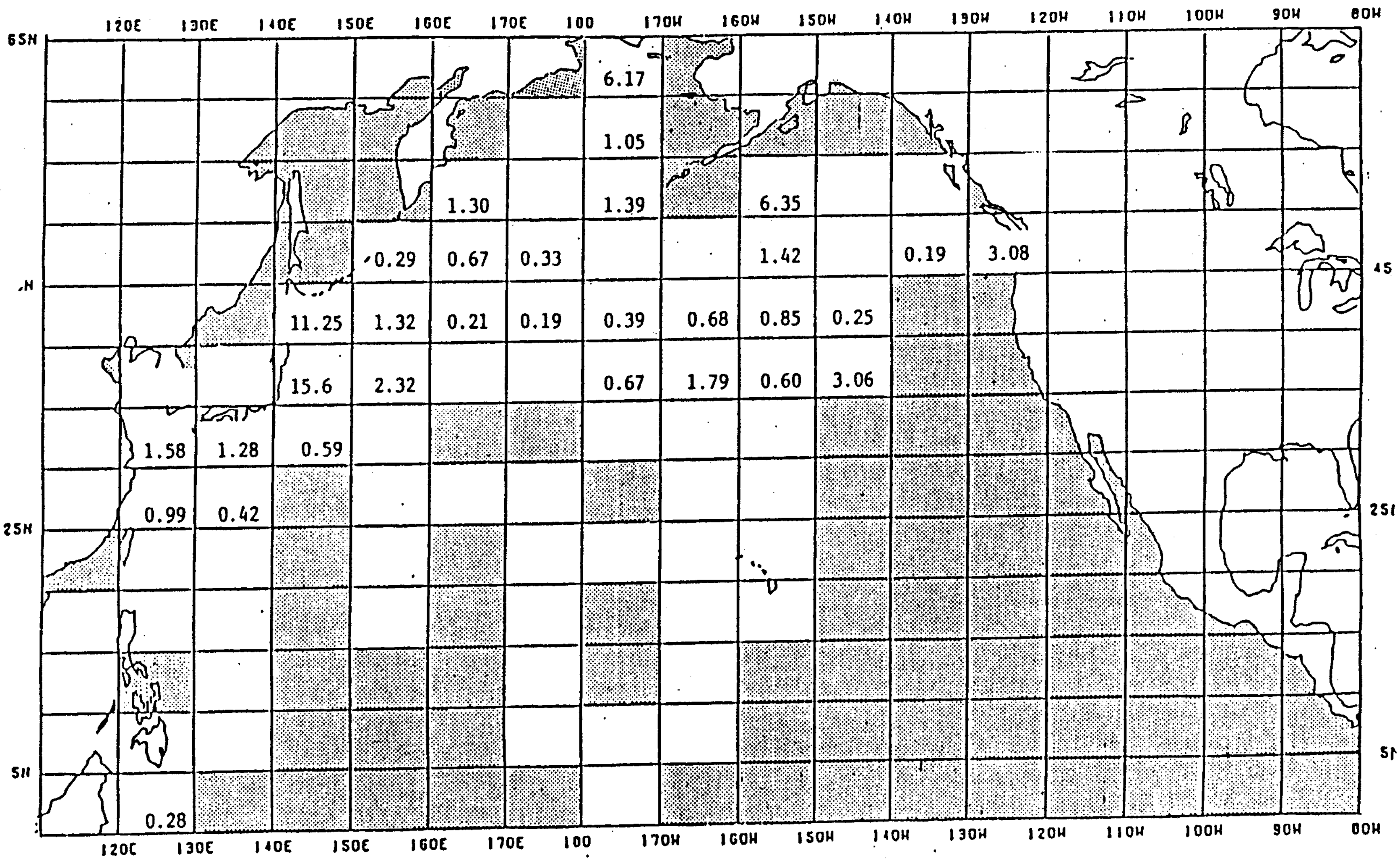


Figure 8G.--Estimated density distribution of other marine debris in 1986.
Unit: number of debris pieces × 10^{-1} per 1 nmi^2.

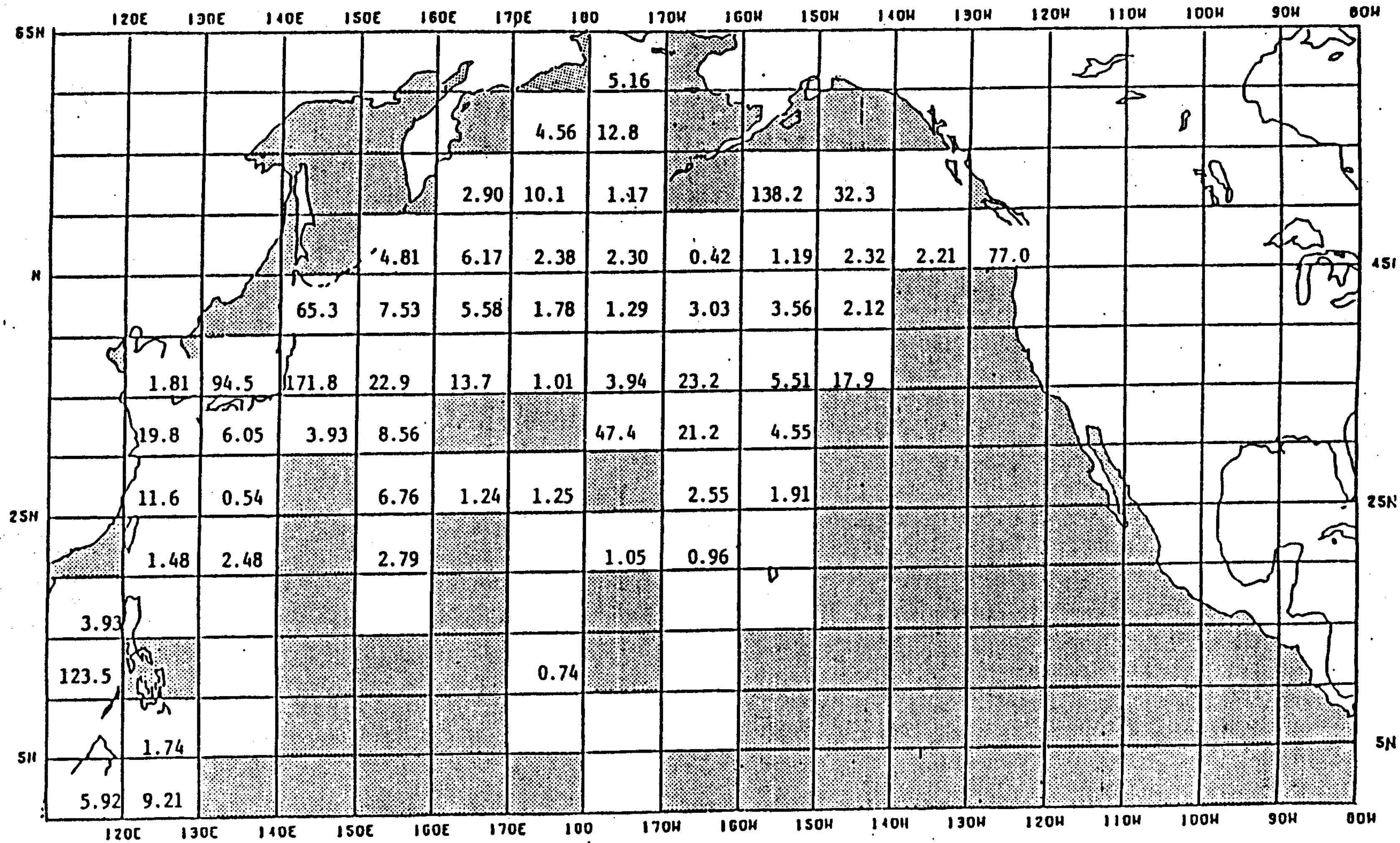


Figure 8H.--Estimated density distribution of total marine debris in 1986.
Unit: number of debris pieces × 10^{-1} per 1 nmi^2.

not only the number of individual items, but also their volume are important elements. However, it is quite difficult to measure with the eye the volume of things having various shapes. Therefore, in the survey we set these very rough size criteria and recorded the sizes of marine debris. Judging from the results by type of marine debris, "small" showed an extremely high rate, except in fishing net, pieces of wood, and drifting logs. In particular, "small" accounted for >90% of other plastic debris and Styrofoam, which were also great in actual volume. Although the number of items of this type of marine debris was great, it is believed that there was no greater difference in quantity than in number between this marine debris and other marine debris. More than half of the "large" items were fishing nets; the number was small, but the volume of each item was large. It is necessary to obtain more information on size in future surveys. It is believed that pieces of wood, drifting logs, and floating seaweed, which occur naturally, constitute the bulk of marine debris because of their large quantity and relatively large size.

These distribution patterns were almost the same as those obtained from the experimental sighting surveys conducted in 1986 (Figs. 7 and 8). It is necessary to study relationships between movement and accumulation of marine debris and ocean currents as well as to collect more data in the future. Furthermore, in order to understand yearly changes, it is also necessary to intensify the surveys in the North Pacific Ocean and adjacent areas and to establish methods of monitoring.

Yagi and Nomura (1988) reported on yearly changes in the density of marine debris based on sighting surveys conducted by the *Ryofu Maru* of the Meteorological Agency twice in winter and summer during 1976-86 using observations lines fixed between the Equator and lat. 34°N along long. 137°E. The survey results are said to be valuable for examining the yearly changes in marine debris using the same blocks at fixed periods each year, although observation blocks were limited in number. The survey results showed that the number of marine debris pieces sighted by unit distance more than doubled from when the survey was first launched. In particular, plastic sheet fragments have shown a marked increase in recent years.

REFERENCES

Mio, S., and S. Takehama.
1987. Distribution of marine debris based on sighting survey in 1986. Document submitted to the Thirty-fourth Annual Meeting of the International North Pacific Fisheries Commission.

Seber, G. A. F.
1982. The estimation of annual abundance and related parameters. Chas. Griffin & Co., Ltd.

Yagi, N., and M. Nomura.
1988. Sighting survey on marine debris in the midwesern Pacific from 1977 through 1986. *In* D. L. Alverson and J.A. June (editors) Proceedings of the North Pacific Rim Fisherman's Conference on Marine Debris, Kailua-Kona, Hawaii, 13-16 October 1987, p. 130-142. Unpublished report by Natural Resources Consultants, 4055 21st Avenue W., Seattle, WA 98199.

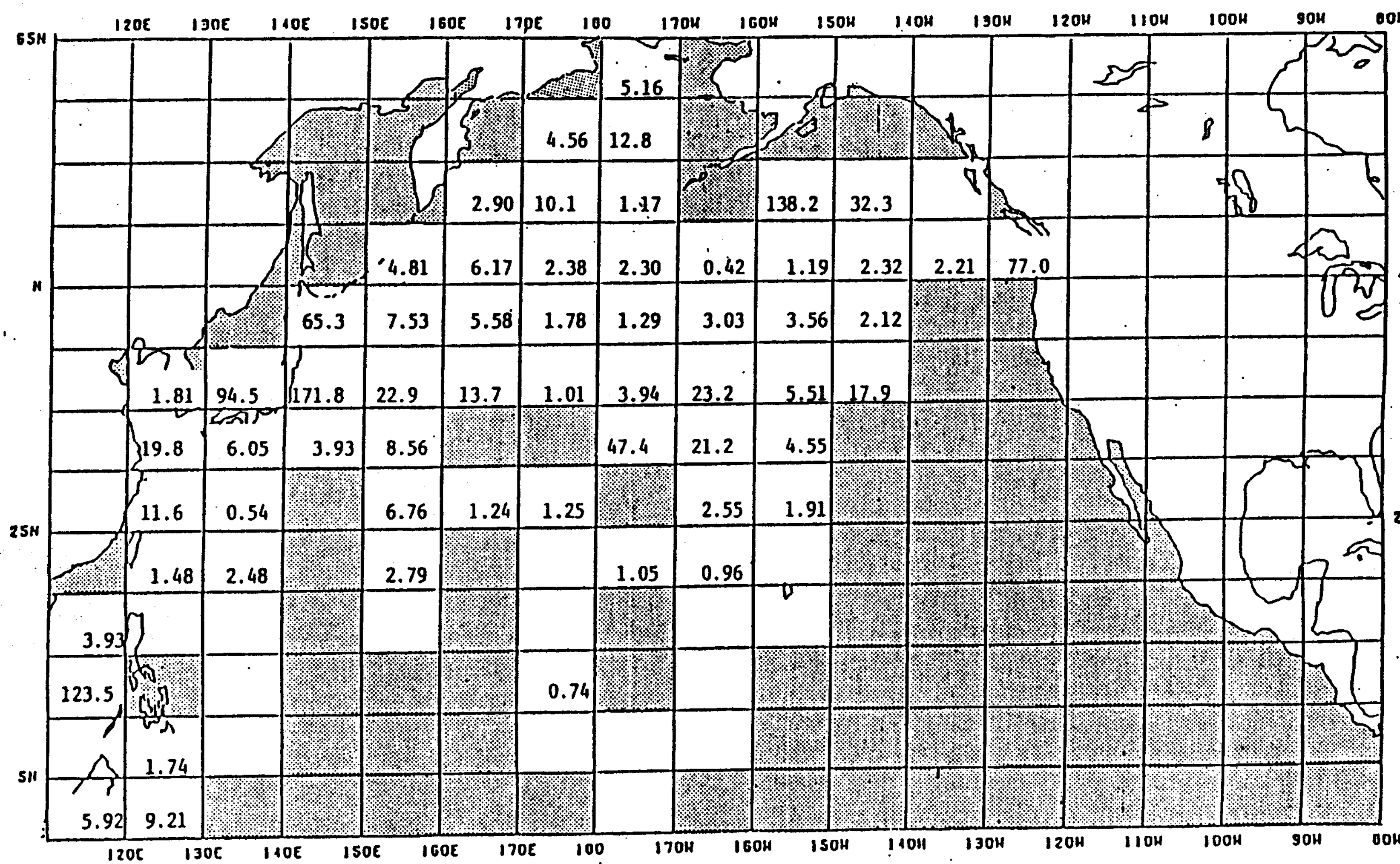


Figure 8H.--Estimated density distribution of total marine debris in 1986.
Unit: number of debris pieces × 10^{-1} per 1 nmi^2.

not only the number of individual items, but also their volume are important elements. However, it is quite difficult to measure with the eye the volume of things having various shapes. Therefore, in the survey we set these very rough size criteria and recorded the sizes of marine debris. Judging from the results by type of marine debris, "small" showed an extremely high rate, except in fishing net, pieces of wood, and drifting logs. In particular, "small" accounted for >90% of other plastic debris and Styrofoam, which were also great in actual volume. Although the number of items of this type of marine debris was great, it is believed that there was no greater difference in quantity than in number between this marine debris and other marine debris. More than half of the "large" items were fishing nets; the number was small, but the volume of each item was large. It is necessary to obtain more information on size in future surveys. It is believed that pieces of wood, drifting logs, and floating seaweed, which occur naturally, constitute the bulk of marine debris because of their large quantity and relatively large size.

These distribution patterns were almost the same as those obtained from the experimental sighting surveys conducted in 1986 (Figs. 7 and 8). It is necessary to study relationships between movement and accumulation of marine debris and ocean currents as well as to collect more data in the future. Furthermore, in order to understand yearly changes, it is also necessary to intensify the surveys in the North Pacific Ocean and adjacent areas and to establish methods of monitoring.

Yagi and Nomura (1988) reported on yearly changes in the density of marine debris based on sighting surveys conducted by the *Ryofu Maru* of the Meteorological Agency twice in winter and summer during 1976-86 using observations lines fixed between the Equator and lat. 34°N along long. 137°E. The survey results are said to be valuable for examining the yearly changes in marine debris using the same blocks at fixed periods each year, although observation blocks were limited in number. The survey results showed that the number of marine debris pieces sighted by unit distance more than doubled from when the survey was first launched. In particular, plastic sheet fragments have shown a marked increase in recent years.

REFERENCES

Mio, S., and S. Takehama.
1987. Distribution of marine debris based on sighting survey in 1986. Document submitted to the Thirty-fourth Annual Meeting of the International North Pacific Fisheries Commission.

Seber, G. A. F.
1982. The estimation of annual abundance and related parameters. Chas. Griffin & Co., Ltd.

Yagi, N., and M. Nomura.
1988. Sighting survey on marine debris in the midwesern Pacific from 1977 through 1986. *In* D. L. Alverson and J.A. June (editors) Proceedings of the North Pacific Rim Fisherman's Conference on Marine Debris, Kailua-Kona, Hawaii, 13-16 October 1987, p. 130-142. Unpublished report by Natural Resources Consultants, 4055 21st Avenue W., Seattle, WA 98199.

THE QUANTITATIVE DISTRIBUTION AND CHARACTERISTICS OF NEUSTON PLASTIC IN THE NORTH PACIFIC OCEAN, 1985-88

Robert H. Day
Alaska Biological Research
P.O. Box 81934
College, Alaska 99708, U.S.A.

David G. Shaw
Institute of Marine Sciences
University of Alaska
Fairbanks, Alaska 99775, U.S.A.

and

Steven E. Ignell
Alaska Fisheries Science Center Auke Bay Laboratory
National Marine Fisheries Service, NOAA
Auke Bay, Alaska 99821, U.S.A.

ABSTRACT

The distribution, abundance, and characteristics of neuston plastic in the North Pacific, Bering Sea, and Japan Sea were studied during the 4-year period 1985-88 at 203 neuston stations encompassing ca. 91,000 m^2 of sampling. The highest total density of neuston plastic was 316,800 pieces/km^2 at lat. 35°59'N, long. 152°00'E in Transitional Water east of Japan. The highest total concentration of neuston plastic was 3,491.8 g/km^2 at lat. 40°00'N, long. 171°30'E near the Subarctic Front in the central North Pacific. Main types of neuston plastic were miscellaneous line fragments (21.7% of all stations), Styrofoam (12.8%), polypropylene line fragments (7.4%), miscellaneous or unidentified plastic (7.4%), and raw pellets (5.9%). Plastic fragments were recorded at 52.2% of all stations and at 88.3% of those stations with plastic. The highest densities (number per square kilometer) and concentrations (gram per square kilometer) of neuston plastic occurred in Japan Sea/nearshore Japan Water, in Transitional Water, and in Subtropical Water. Densities of neuston plastic in Subarctic Water and Bering Sea Water were low. Heterogeneous geographic input and currents and winds are important in distributing and concentrating neuston plastic. Microscale convergences appear to be important mechanisms that locally concentrate neuston plastic, increasing the probability of its entering food chains.

In R. S. Shomura and M. L. Godfrey (editors), Proceedings of the Second International Conference on Marine Debris, 2-7 April 1989, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-154. 1990.

INTRODUCTION

Marine debris, especially plastic debris, increasingly is recognized as a national and international pollution problem (Shomura and Yoshida 1985; Wolfe 1987). Plastic enters the ocean in many forms and many sizes. In addition to plastic objects associated with ships (e.g., lines, nets, floats), virtually every kind of plastic packaging and plastic object used on land may be discarded or lost to the sea. Some plastics are denser than seawater and thus sink, but some are buoyant enough to float, either because of trapped gas or because of low specific gravity. At sea, plastic objects undergo mechanical breakdown or fragmentation, leading to progressively smaller pieces of floating plastic. The size fraction of plastic debris caught in nets designed to catch surface plankton (hereafter referred to as neuston plastic) is of interest for several reasons. First, small plastic objects are more abundant than are the larger ones from which they are formed. Second, collection of plastic in nets is an objective process that provides unbiased estimates of densities. Finally, objects in this size range can be mistaken for food items, with possibly important ecological consequences (Day 1980; Day et al. 1985).

Several workers have investigated the distribution of neuston plastic in the North Pacific (Wong et al. 1974; Shaw 1977; Shaw and Mapes 1979; Day et al. 1985; Day and Shaw 1987). These studies have shown that neuston plastic is widespread, is most abundant in the central and western North Pacific, and is distributed by currents and winds.

The goal of this study was to improve our knowledge of the quantitative distribution and characteristics of neuston plastic in the North Pacific Ocean. Specifically, we wanted to: (1) describe the quantitative distributions of the main types of neuston plastic, (2) compare the at-sea densities of the main neuston types, (3) describe the frequencies of colors of neuston plastic, and (4) examine the importance of currents and winds in affecting the quantitative distribution of neuston plastic. Because of the extensive geographic coverage of the work, this study provides one of the most detailed synoptic pictures of neuston plastic anywhere in the world ocean.

METHODS

We collected data on the density, concentration, and types of neuston plastic ≥0.500 mm in size at 203 neuston stations in the North Pacific Ocean north of lat. 21°N (i.e., Hawaii) and in the Bering and Japan Seas. At each station, a 1.3-m ring net (during 1985) or a Sameoto (Sameoto and Jaroszynski 1969) neuston sampler (1986-88) with a 0.500-mm mesh net was used to collect neuston samples. Following Day and Shaw (1987), the area of ocean's surface sampled was calculated by multiplying the width of the net opening (0.5 m for the Sameoto sampler; see Day and Shaw 1987 for information on the ring net) by the distance the ship traveled in 10 min of sampling at a known speed, corrected for the time that the net was not fishing. Samples were washed from the net and either were sorted on the ship or were preserved in formalin and sorted later in the laboratory. Although areas sampled varied among stations, we ignored these differences among stations in the analyses. Data from 1985 that already were published (32 stations, Day and Shaw 1987) were included here because that number is small compared with the 171 stations for which the data have not been published.

During sorting, individual pieces of plastic were counted and identified as one of six standardized types: pellet, fragment, Styrofoam (which may include foamed plastics of other chemical composition), polypropylene line (which may include synthetic line of other chemical composition), miscellaneous or unidentified line, and miscellaneous or unidentified plastic. These pieces of plastic also were identified as 1 of 11 standardized colors: black/gray, blue, brown, green, orange, red/pink, tan, transparent, white, yellow, and mixed or unidentified. The samples then were placed in preweighed vials and were air-dried before being weighed to the nearest 0.001 g.

Data were compiled as the total density (number per square kilometer) and total concentration (mass per square kilometer) of neuston plastic at each station and as the density of each general type of plastic at each station. The color data were compiled as the numbers and frequencies of occurrence of each color at each station and were tabulated as total frequencies of each color. For data analysis, each station was stratified geographically into one of five water masses: Bering Sea Water, Subarctic Water (north of the Subarctic Front, or north of ca. lat. 42°N), Subtropical Water (south of the Subtropical Front, or south of ca. lat. 31°N), Japan Sea/nearshore Japan Water (the latter area consisting of water east of Japan and west of lat. 150°E), and Transitional Water (that between Subarctic Water and Subtropical Water, and including the Subarctic Frontal Zone, the Transition Zone, and the Subtropical Front).

The stratified data on total density, total concentration, and densities of each type of neuston plastic were analyzed with a Kruskal-Wallis test (Conover 1980; Zar 1984). For each data set, we tested the hypothesis:

> H_0: The density (or concentration) does not differ among water masses.

When test results were significant, we conducted multiple comparisons tests (Conover 1980) to determine which water masses were different. We also calculated means and standard deviations of each data set in each water mass. The color data were compiled as frequencies of each color of plastic. Subsequently, these frequencies were divided by the total number of plastic items to determine percentages of each color type.

RESULTS

Neuston plastic was recorded at 120 stations (59.1% of total stations); the total number of pieces recorded was 1,774. The two water masses in which plastic occurred at 100% of the stations were Subtropical Water (n = 2 stations) and Japan Sea/nearshore Japan Water (n = 11 stations). Neuston plastic also was common in Transitional Water, where it occurred at 56 (93.3%) of 60 stations, and in Subarctic Water, where it occurred at 46 (71.9%) of 64 stations. Finally, it was uncommon in Bering Sea Water, where it occurred at only 5 (7.6%) of 66 stations.

Total Density

Total densities of neuston plastic were highest in the Japan Sea, in nearshore water east of Japan, and in Transitional Water and the Subarctic Front; total densities generally were very low in Subarctic Water (especially in the center of the Alaska Gyre) and in the Bering Sea (Fig. 1). The highest total density of neuston plastic was 316,800 pieces/km^2 at lat. 35°59'N, long. 152°00'E in Transitional Water east of Japan. Other stations with high total densities were 221,000 pieces/km^2 at lat. 38°55'N, long. 135°58'E in the Japan Sea; 217,300 pieces/km^2 at lat. 37°58'N, long. 52°00'E near the Subarctic Front east of Japan; and 202,700 pieces/km^2 at lat. 40°00'N, long. 174°30'E near the Subarctic Front in the central North Pacific. Total densities differed significantly among water masses ($H = 1221.482$; $n = 203$; df = 4; $P < 0.05$; Table 1). Multiple comparisons indicated that densities were: Japan Sea/nearshore Japan Water = Subtropical Water = Transitional Water > Subarctic Water > Bering Sea Water.

Concentration

Total concentrations of neuston plastic generally were low, with high concentrations recorded at only four stations in Transitional Water, at two stations in nearshore water east of Japan, and at one station in Subarctic Water; total concentrations at the other stations with plastic generally were <10% of the highest concentration (Fig. 2). The highest total concentration was 3,941.8 g/km^2 at lat. 40°00'N, long. 171°30'E near the Subarctic Front in the central North Pacific. Other concentrations >1,000 g/km^2 were 3,007.9 g/km^2 at lat. 37°58'N, long. 152°00'E near the Subarctic Front east of Japan, 1,979.1 g/km^2 at lat. 35°59'N, long. 152°00'E in Transitional Water east of Japan, and 1,048.5 g/km^2 at lat. 28°20'N, long. 162°20'W in Subtropical Water north of the Hawaiian Islands. Total concentrations differed among water masses ($H = 120.604$; $n = 203$; df = 4; $P < 0.05$; Table 1). Multiple comparisons indicated that concentrations were: Subtropical Water = Japan Sea/nearshore Japan Water = Transitional Water > Subarctic Water > Bering Sea Water. The similarity in patterns between total densities and total concentrations is understandable, considering the strong correlation between these two parameters (Spearman's $R = 0.905$; $Z = 12.861$; $n = 203$; $P < 0.05$; Conover 1980; Zar 1984). The Pearson's product-moment correlation between these parameters was not as high, however ($r = 0.544$; $n = 203$; $P < 0.05$).

Pellets

In the plastics industry, plastic resins commonly are manufactured as cylindrical pellets a few millimeters in size. Later, these pellets are melted and molded into finished products. Pellets were uncommon, being recorded only 12 times (5.9% of total stations and 10.0% of stations with plastic). Pellets were absent in the Bering and Japan Seas, were recorded only once in Subarctic Water, and were recorded primarily in Transitional

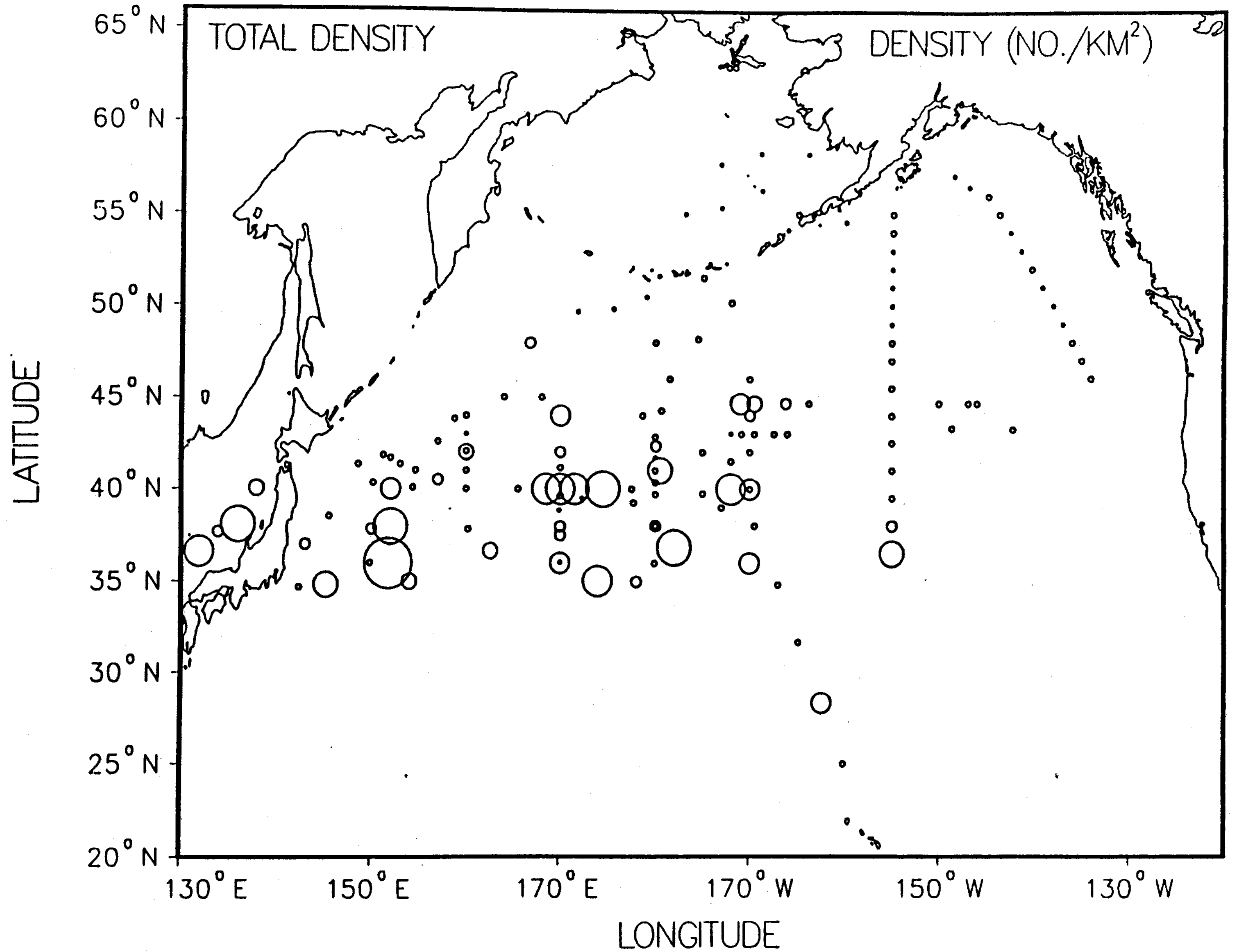


Figure 1.--Total densities of neuston plastic, 1985-88. Solid black circles indicate stations at which neuston plastic was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 316,800 pieces/km^2.

Table 1.--Densities (number per square kilometer) and concentrations (grams per square kilometer) of neuston plastic in five water masses of the North Pacific, 1985-88.

Parameter	Bering Sea Water		Subarctic Water		Transitional Water		Subtropical Water		Japan Sea and nearshore Japan Water	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Number	66		64		60		2		11	
Area sampled (m^2)	35,906		28,662		22,154		541		3,824	
Total concentration	1.0	4.2	61.4	225.5	291.6	714.4	535.1	726.1	128.2	172.2
Total density	100	600	12,800	22,300	57,900	72,800	61,000	74,000	74,700	73,800
Pellet	0	0	<100	300	300	800	3,300	4,600	500	1,200
Fragment	0	0	9,600	20,300	52,700	69,200	57,700	69,400	46,100	40,000
Styrofoam	0	0	400	1,300	1,100	3,200	0	0	26,200	37,200
Polypropylene line	100	400	400	1,500	500	1,500	0	0	0	0
Miscellaneous line/thread	100	300	2,600	6,900	2,300	4,600	0	0	1,900	3,300
Miscellaneous/unidentified	100	500	100	500	1,000	3,100	0	0	0	0

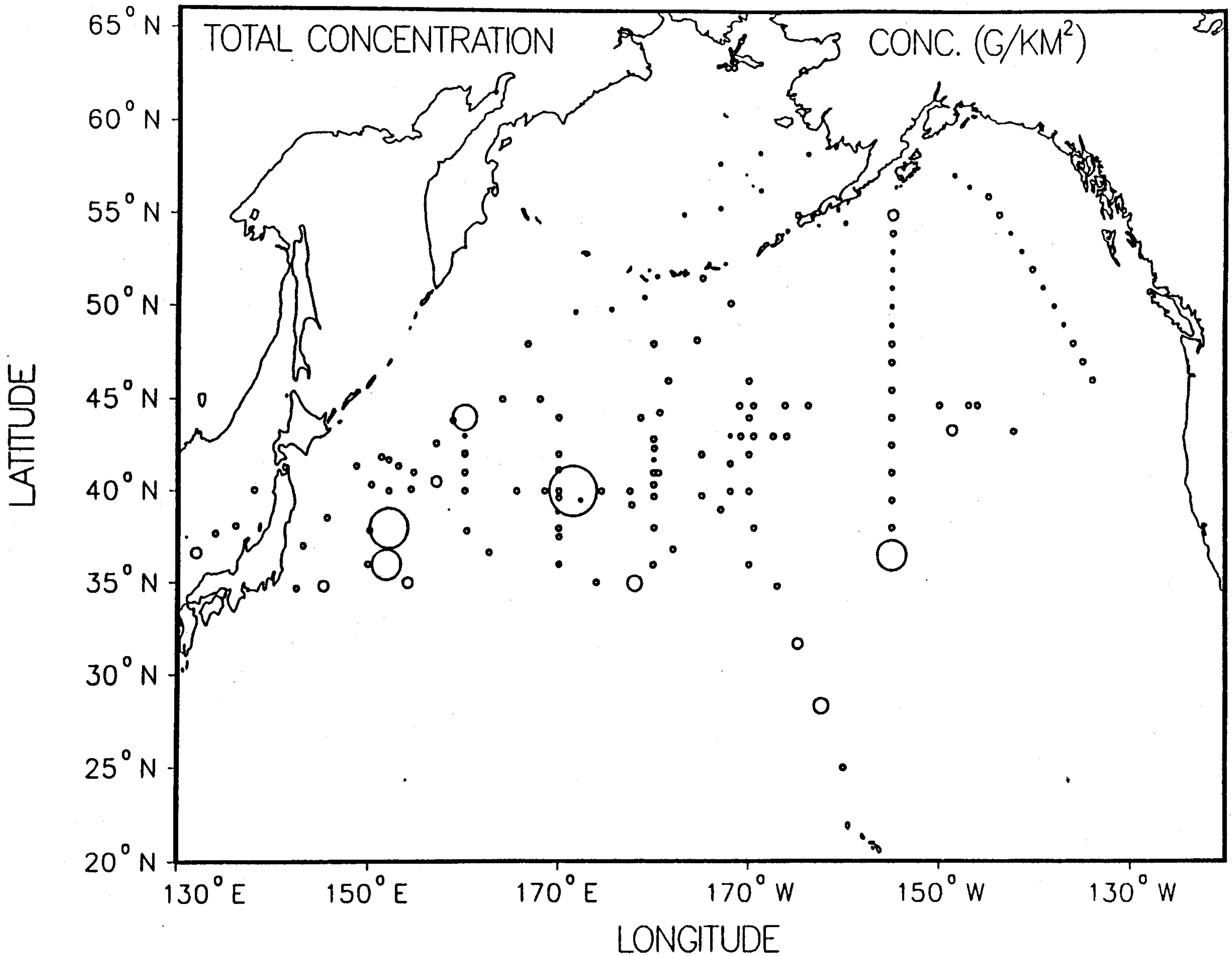


Figure 2.--Total concentrations of neuston plastic, 1985-88. Solid black circles indicate stations at which neuston plastic was not recorded. Sizes of hollow circles indicate relative densities. The highest concentration was 3,941.8 g/km^2.

Water and in nearshore water east of Japan (Fig. 3). The highest density was 6,500 pieces/km^2 at lat. 28°20'N, long. 162°20'W in Subtropical Water north of the Hawaiian Islands. The density of pellets differed among water masses ($H = 22.996$; $n = 203$; $df = 4$; $P < 0.05$; Table 1). Multiple comparisons were confusing, however, in that none of the individual water masses were significantly different. We suspect that the significant result was an artifact of the presence of pellets at both of the two stations in Subtropical Water. Consequently, the mean rank in this water mass was much higher than those in the other water masses, although the small sample size made it impossible to prove that significant differences actually existed.

Fragments

Fragments are small pieces of plastic broken from larger pieces (excluding Styrofoam). This category included primarily chips and pieces of sheets. Fragments were common, being recorded at 106 stations (52.2% of total stations and 88.3% of all stations with plastic). Fragments were common except in the Bering Sea and occurred in highest densities in nearshore water east of Japan and in and around the Subarctic Front; densities were lower in the Japan Sea and Subtropical Water and were much lower in Subarctic Water (Fig. 4). The highest density was 288,000 pieces/km^2 at lat. 35°59'N, long. 152°00'E in Transitional Water east of Japan. Other stations with high densities of fragments were 202,700 pieces/km^2 at lat. 40°00'N, long. 174°30'E near the Subarctic Front in the central North Pacific; and 199,000 pieces/km^2 at lat. 37°58'N, long. 152°00'E near the Subarctic Front east of Japan. The density of fragments differed significantly among water masses ($H = 113.587$; $n = 203$; $df = 4$; $P < 0.05$; Table 1). Multiple comparisons indicated that densities were: Japan Sea/nearshore Japan Water = Subtropical Water = Transitional Water > Subarctic Water > Bering Sea Water.

Styrofoam

This category included all pieces of pieces of foamed plastic; based on observed color and texture, we believe that all of this plastic was polystyrene. Styrofoam was uncommon, being recorded only 26 times (12.8% of total stations and 21.7% of stations with plastic). It was recorded in all locations except the Bering Sea and Subtropical Water, and occurred in highest densities in the Japan Sea and nearshore water east of Japan. It was a "transitional/nearshore Japan species," being recorded outside of this area only five times (Fig. 5). The highest density was 99,500 pieces/km^2 at lat. 36°37'N, long. 131°54'E in the Japan Sea. Other stations with high densities were 82,200 pieces/km^2 at lat. 38°55'N, long. 135°58'E in the Japan Sea; and 65,400 pieces/km^2 at lat. 34°49'N, long. 144°55'E off the eastern coast of Japan. Densities of Styrofoam differed significantly among water masses ($H = 52.967$; $n = 203$; $df = 4$; $P < 0.05$; Table 1). Multiple comparisons indicated that densities were: Japan Sea/nearshore Japan Water > Transitional Water = Subarctic Water = Subtropical Water.

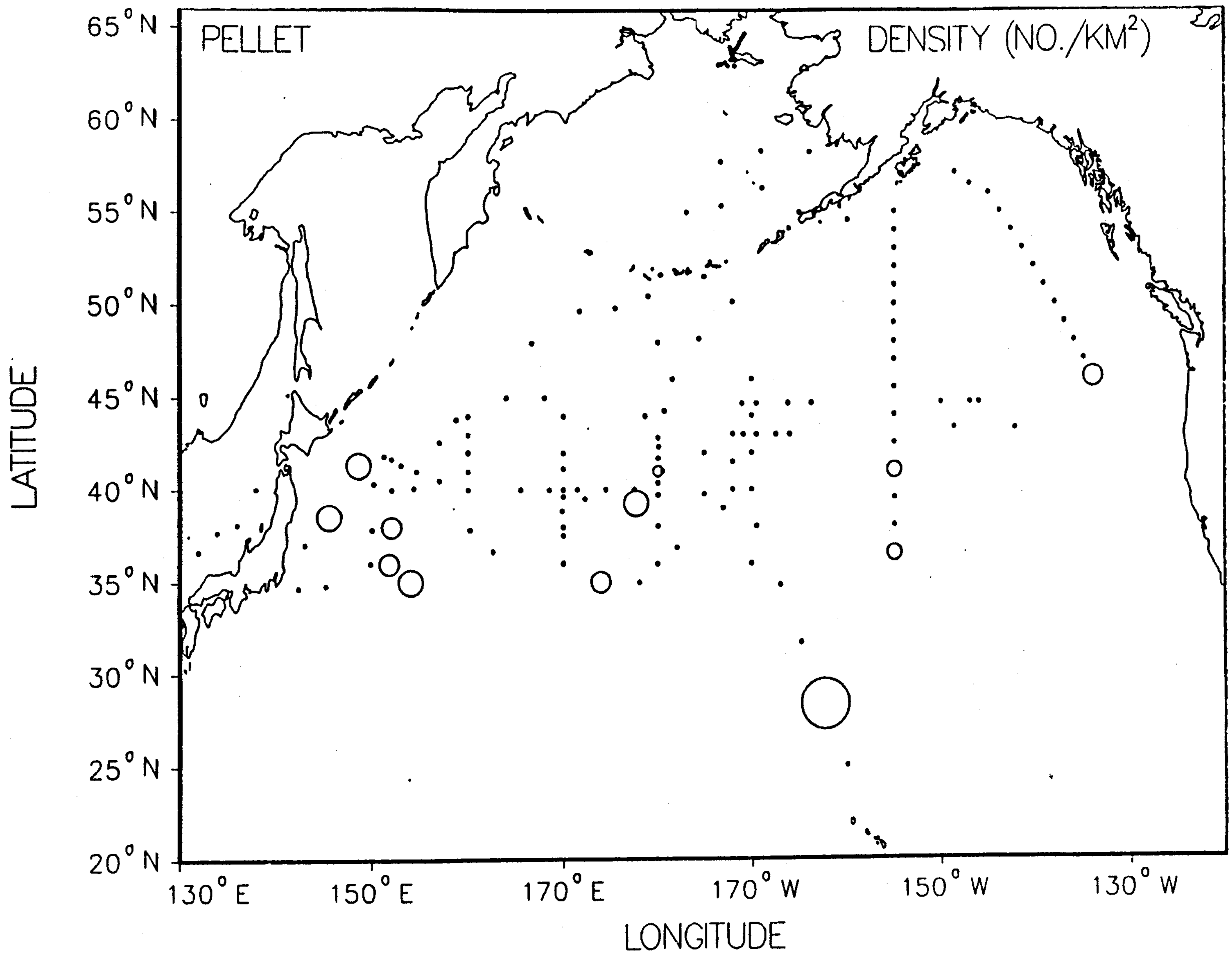


Figure 3.--Densities of pellets, 1985-88. Solid black circles indicate stations at which neuston plastic was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 6,500 pieces/km^2.

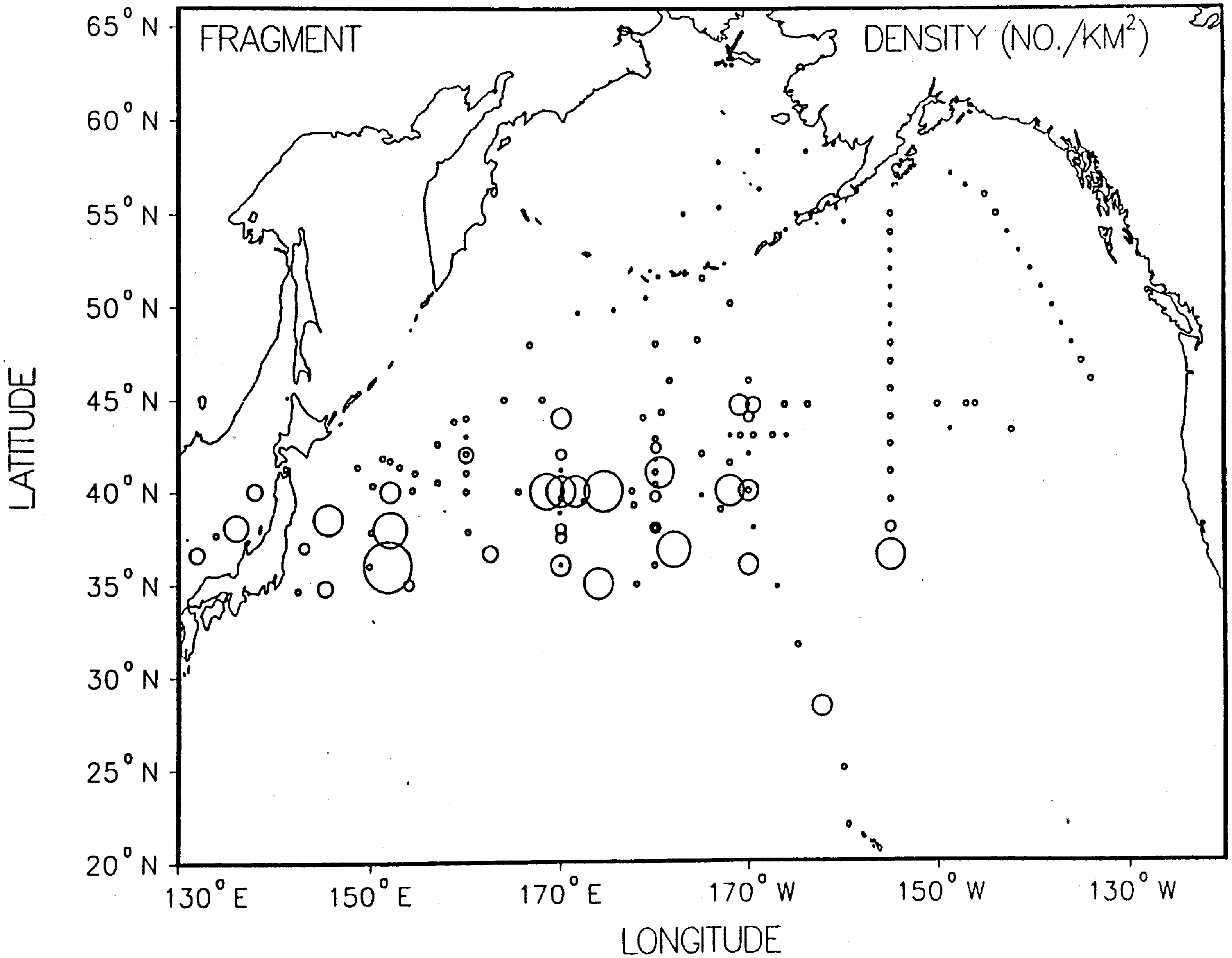


Figure 4.--Densities of fragments, 1985-88. Solid black circles indicate stations at which neuston plastic was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 288,000 pieces/km^2.

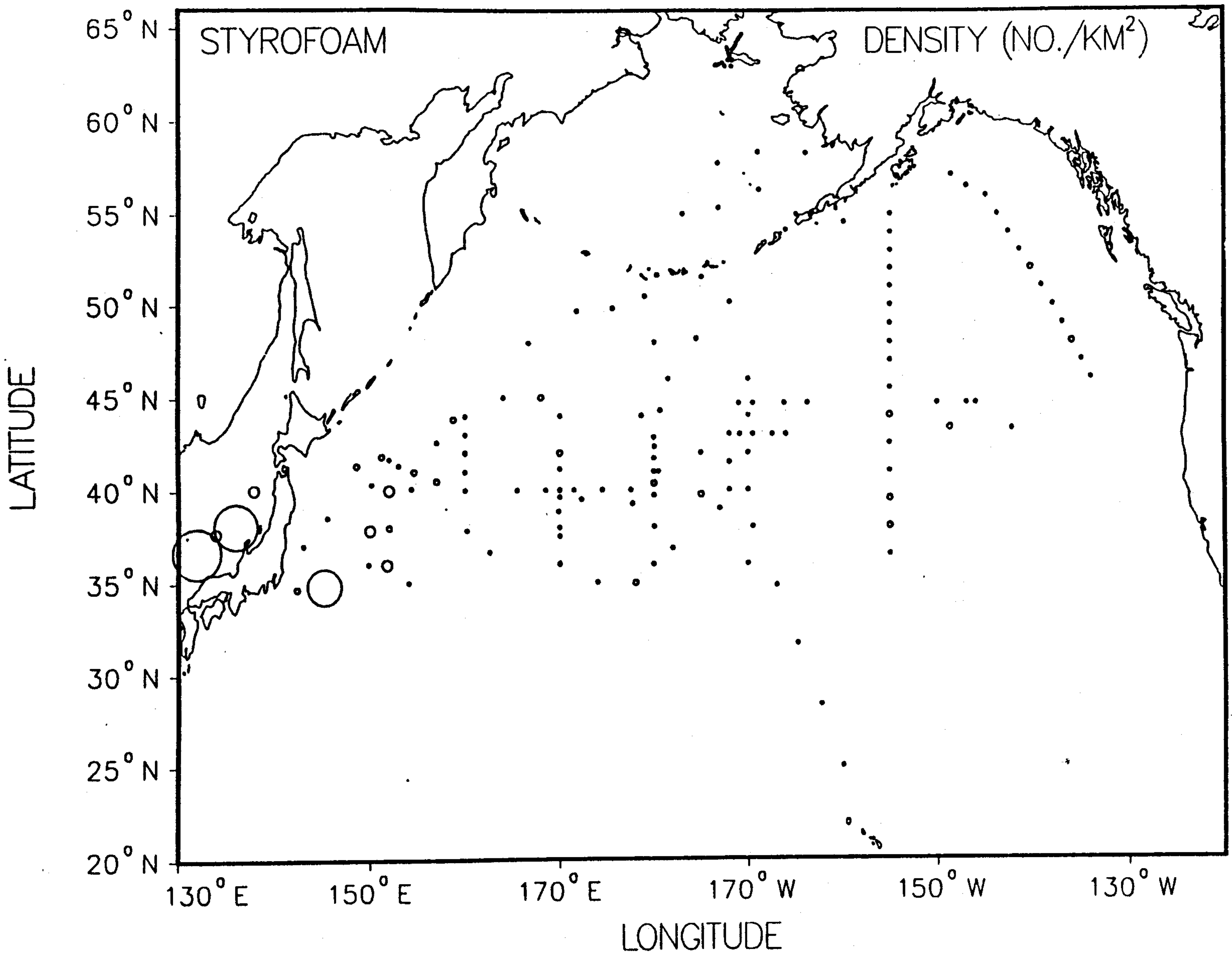


Figure 5.--Densities of Styrofoam, 1985-88. Solid black circles indicate stations at which neuston plastic was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 99,500 pieces/km^2.

Polypropylene Line Fragments

Polypropylene line fragments are small, woven pieces of large synthetic lines that are used as deck lines on fishing boats and cargo ships. Polypropylene is the most commonly used plastic for these applications. These line fragments were uncommon, being recorded 15 times (7.4% of total stations and 12.5% of stations with plastic). Polypropylene line fragments occurred primarily in and near the Subarctic Front and in Transitional Water; they were absent in the Japan Sea and in Subtropical Water (Fig. 6). The highest density was 8,400 pieces/km^2 at lat. 41°09'N, long. 170°00'E near the Subarctic Front in the central North Pacific. We failed to reject the null hypothesis that the density of polypropylene line fragments did not differ significantly among water masses ($H = 3.597$; $n = 203$; $df = 4$; $P > 0.05$; Table 1), probably because densities were low everywhere.

Miscellaneous Lines/Threads

Miscellaneous lines and threads included unidentified woven line fragments and (especially) monofilament lines that were from either gillnets or monofilament fishing line. We do not know what type of plastic they were, but they probably were not nylon, as it does not float (Carpenter 1976). Miscellaneous lines/threads were somewhat common, being recorded 44 times (21.7% of total stations and 36.7% of stations with plastic). They were recorded in all but Subtropical Water, with the highest densities occurring east of Japan and near the Subarctic Front (Fig. 7); they possibly may be fragments of line used by squid jiggers, which fish in this area. The highest density was 40,500 pieces/km^2 at lat. 47°59'N, long. 166°41'E in western Subarctic Water. Densities of miscellaneous lines/threads differed significantly among water masses ($H = 24.607$; $n = 203$; $df = 4$; $P < 0.05$; Table 1). Multiple comparisons were confusing, however, in that those water masses with the largest difference in mean ranks were not significantly different, whereas water masses with smaller differences in mean ranks were significantly different. The two water masses that were significantly different were Transitional Water > Bering Sea Water, two with large sample sizes (60 and 66, respectively). We suspect that other water masses were different but that sample sizes in most were too small for the multiple comparisons to show significant differences. The pattern of mean ranks (in descending order) was: Japan Sea/nearshore Japan Water, Transitional Water, Subarctic Water, Bering Sea Water, and Subtropical Water.

Colors of Neuston Plastic

Most neuston plastic was transparent. This color was recorded 785 times (44.3% of the total 1,774 pieces and 44.9% of plastic of identified color). White plastic also was abundant, being recorded 610 times (34.4% of the total and 34.9% of plastic of identified color), followed by blue (128 pieces; 7.2% of the total and 7.3% of plastic of identified color), black/gray (74 pieces; 4.2% and 4.2%), green (62 pieces; 3.5% and 3.5%), and tan (45; 2.5% and 2.6%). The colors brown (17 pieces; 1.0% and 1.0%), red/pink (13 pieces; 0.7% and 0.7%), yellow (8 pieces; 0.5% and 0.5%), and orange (5 pieces; 0.3% and 0.3%) were rare in occurrence. Miscellaneous or unidentified colors occurred 27 times (1.5%).

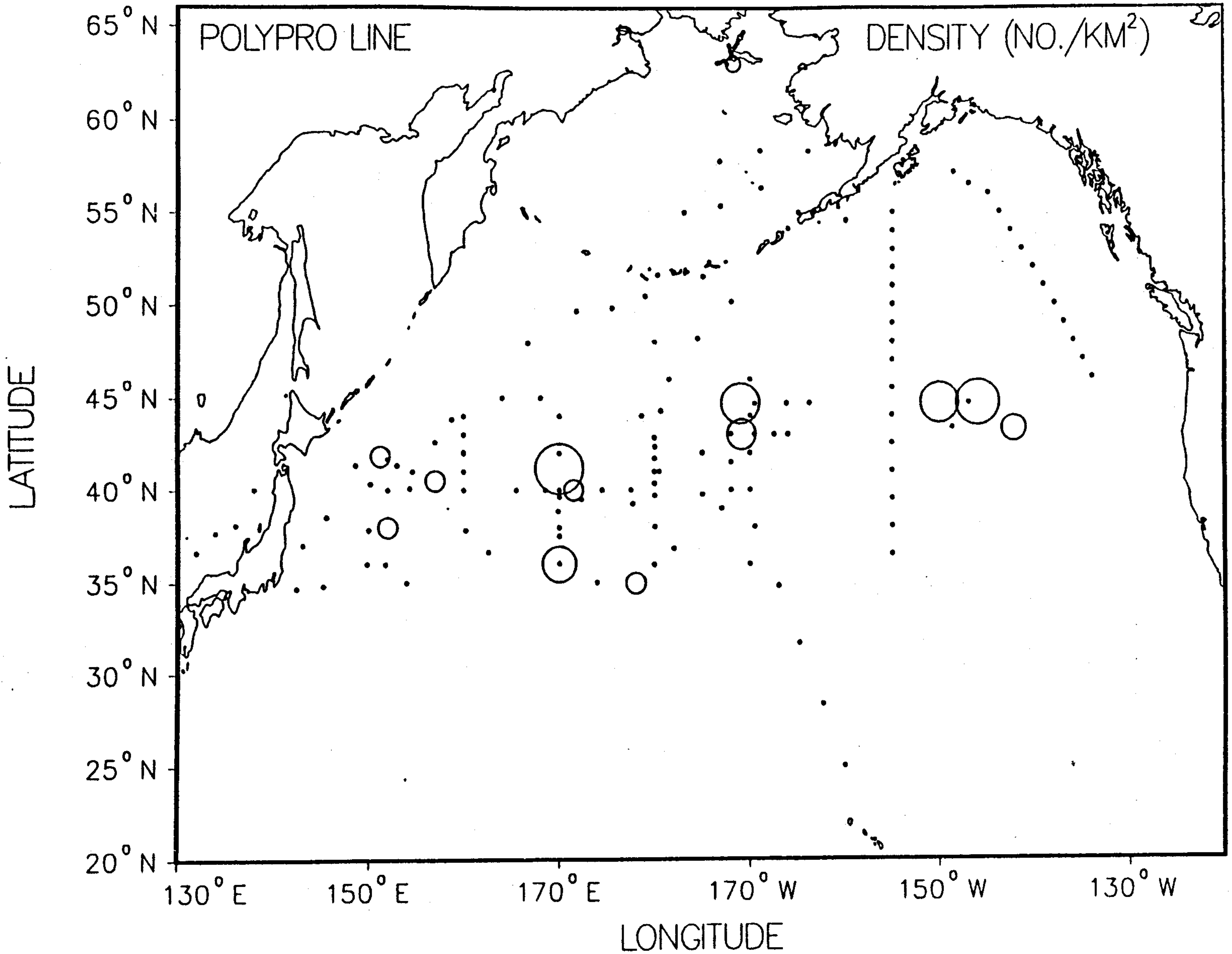


Figure 6.--Densities of polypropylene line fragments, 1985-88. Solid black circles indicate stations at which neuston plastic was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 8,400 pieces/km^2.

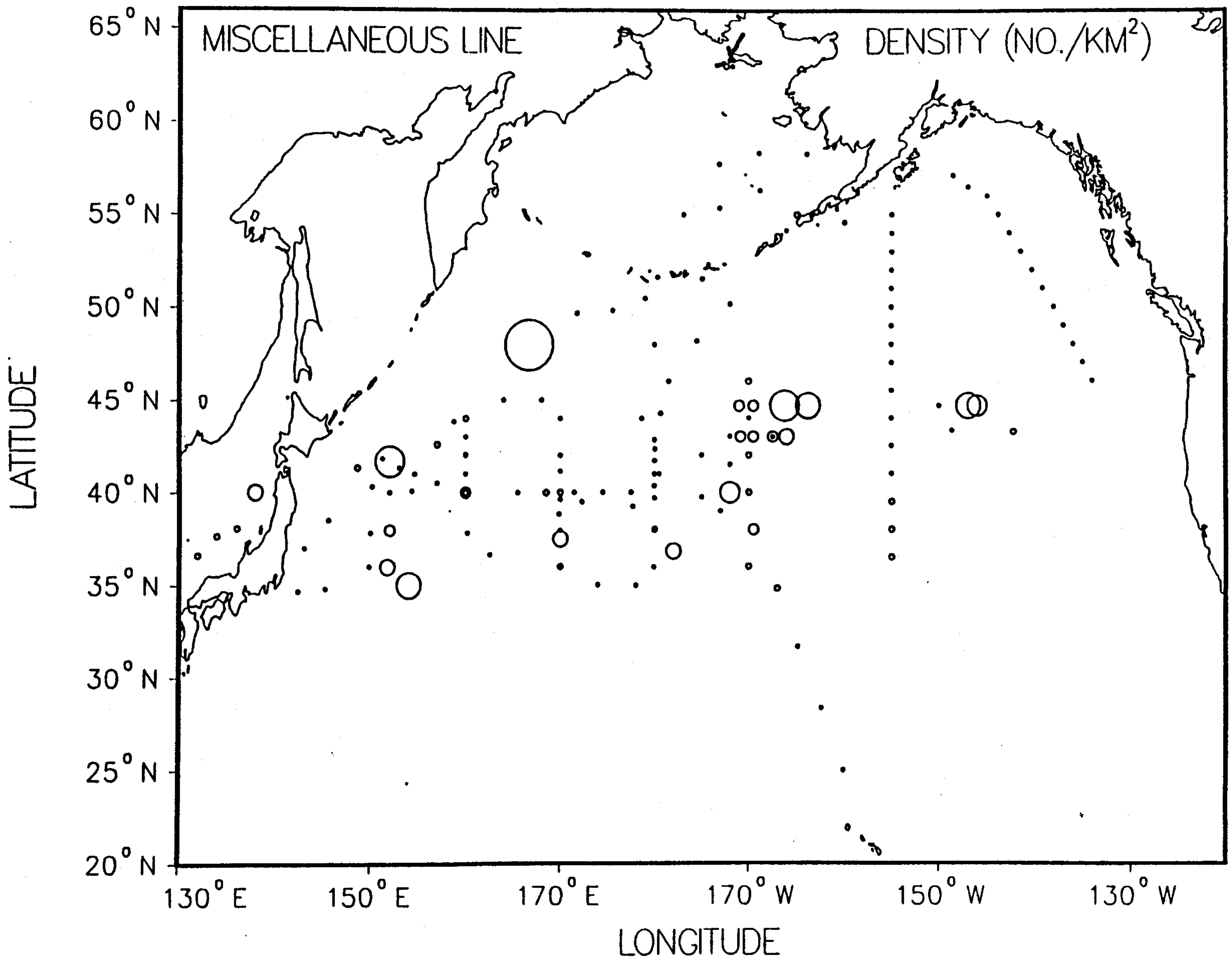


Figure 7.--Densities of miscellaneous lines/threads, 1985-88. Solid black circles indicate stations at which neuston plastic was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 40,500 pieces/km^2.

DISCUSSION

The distribution of neuston plastic results from two main phenomena, heterogeneous geographic input of plastic and subsequent redistribution by currents and winds. In addition, a phenomenon of unknown importance is the in situ decomposition of plastic in the ocean.

It appears that there is heterogeneous geographic input of neuston plastic, with much of it originating in the western Pacific. This conclusion is indicated by the high densities in and around the Japan Sea and nearshore Japan, where the highest densities of both neuston plastic and marine debris (Day et al. 1990) were recorded. The most polluted water in this area were Tokyo Bay (which had far more plastic than Day has ever seen elsewhere in the Pacific--he was unable to sample there) and localized areas in the Japan Sea. At the other extreme was the poorly populated Bering Sea area, where low rates of input probably occur. The low human population around much of the Gulf of Alaska probably contributes to the low densities there, also.

After entering the ocean, however, neuston plastic is redistributed by currents and winds. For example, plastic entering the ocean in Japan is moved eastward by the Subarctic Current (in Subarctic Water) and the Kuroshio (in Transitional Water, Kawai 1972; Favorite et al. 1976; Nagata et al. 1986). In this way, the plastic is transported from high-density areas to low-density areas. In addition to this eastward movement, Ekman stress from winds tends to move surface waters from the subarctic and the subtropics toward the Transitional Water mass as a whole (see Roden 1970: fig. 5). Because of the convergent nature of this Ekman flow, densities tend to be high in Transitional Water. In addition, the generally convergent nature of water in the North Pacific Central Gyre (Masuzawa 1972) should result in high densities there also.

One point that is not entirely clear is the cause of the low densities of neuston plastic in Subarctic Water. Part of the reason for these low densities is the apparently low input from shipping in this area: densities of both neuston plastic and marine debris in this area are low, suggesting little input from ships. The role of the divergent Alaska Gyre in helping to maintain these low densities is unclear, however. For example, neuston plastic tends to concentrate near the edges of the subarctic water mass, with little occurring in its center (Fig. 1), as would be expected for an upwelling gyre. On the other hand, the rate of vertical advection (in the low hundreds of meters/year, with downwelling occurring much of the year; T. C. Royer, Institute of Marine Sciences, University of Alaska, Fairbanks, Alaska, pers. commun.) is much lower than the rate of lateral advection (ca. 3,000 km/year at a speed of 15 cm/sec; Favorite et al. 1976), which should result in upwelling having little effect on the distribution of neuston plastic in this gyre.

A third factor, and one of unknown importance, is the in situ decomposition of larger marine debris plastic into small neuston plastic. As discussed by Day and Shaw (1987), the small percentage of raw plastic pellets and the high correlation between abundances of debris plastic and neuston plastic suggested that in situ decomposition was occurring. Although the present study did not test this hypothesis, we believe that the in situ decomposition of plastic can be important. The large pool of debris plastic and neuston plastic (particularly fragments) in Transitional Water probably is resident for a long period of time and appears to be decomposing there. For example, our impression was that transparent neuston plastic in this area tended to be opaque on the surface, to have more surface crazing (Gregory 1978, 1983), and to be more brittle than did most from Subarctic Water, where it tended to be more transparent on the surface and more pliable. The same phenomenon was true for much of the marine debris plastic in Transitional Water, where it was heavily bleached and heavily encrusted, suggesting long residence time. In reality, however, chemical weathering (leaching of plasticizers from the plastic matrix, causing the remaining plastic to be brittle and more susceptible to mechanical weathering), thermal weathering (increasing the rate of chemical weathering), and solar weathering (from strong sunlight) probably are most important in the in situ production of fragments of neuston plastic in Transitional and Subtropical Waters, whereas mechanical weathering (from rough seas) probably is most important in stormier Subarctic Waters. Finally, thermal (i.e., freezing) and mechanical weathering probably are most important in the stormy, cool Bering Sea, which is ice-covered in winter.

Frequencies of colors of neuston plastic in the North Pacific differed from frequencies of colors of neuston plastic ingested by seabirds (Day et al. 1985). For example, white, yellow, tan, and brown neuston plastic (light colors) represented only 40.0% of total identified neuston plastic in the ocean, whereas it represented 85.0% of neuston plastic ingested by seabirds. One of the largest differences was in tan plastic, which composed only 2.6% of the identified neuston plastic in the ocean but 55.1% of the neuston plastic eaten by seabirds. The largest difference was in transparent plastic, which represented 44.9% of the identified neuston plastic in the ocean but was not found in seabirds. Transparent plastic is not eaten by birds, probably because of difficulty in seeing it at sea (Day et al. 1985).

Neuston plastic can enter food chains when it is mistaken for prey (Day et al. 1985), especially where it becomes concentrated near important, localized prey. For example, there appeared to be a relationship between high densities of neuston plastic and high densities of water-striders, *Halobates sericeus* (Insecta: Gerridae) in Transitional and Subtropical Waters. These marine insects live at the surface of the ocean and are eaten by at least nine species of tropical seabirds that breed in the Hawaiian Islands and feed in these water masses. Water-striders are especially important prey of blue-gray noddies, *Procelsterna cerulea*, Bulwer's petrels, *Bulweria bulwerii*, and Bonin petrels, *Pterodroma hypoleuca*, with the latter two species also containing significant amounts of neuston plastic (Harrison et al. 1983; Cheng et al. 1984). We suspect that these insects are moved slowly into microscale convergences at the same time that plastic and other organisms are. For example, the density of water-striders was 136,000/km^2 at one station where the density of neuston plastic was 113,300 pieces/km^2; the highest density of water-striders was ca. 250,000/km^2 (Day unpubl. data). Given the co-occurrence of water-striders and neuston plastic in some tropical seabirds, we suggest that many of these birds are feeding in these microscale convergences, where they are picking up water-striders, other plankters, and neuston plastic. Indeed, Day has seen surface-feeding planktivorous seabirds (phalaropes and storm-petrels) feeding in large numbers in microscale convergences in the Oyashio-Kuroshio Confluence. These convergences contained visible lines of kelp wrack, plastic, and other marine debris.

Another group that ingests neuston plastic as well as planktonic prey in coastal and oceanic microscale convergences is sea turtles (Carr 1987). Young turtles apparently feed in these convergences during the first year or more at sea, when they drift with the currents and hence act much like neuston plastic. (During this period they also may become entangled in marine debris plastic.) Later, as they become older, these turtles both ingest larger pieces of marine debris plastic and become entangled in marine debris plastic (Balazs 1985).

Microscale convergences may be found in many areas of the world ocean (e.g., Owen 1981; Bourne and Clark 1984), and they may occur in areas different from the general areas of concentration discussed above. From our experience, microscale convergences concentrating neuston plastic are near lat. 28°-29°N north of Hawaii; in and near the Subarctic Front as microscale ephemeral convergences; in the complex Oyashio-Kuroshio Confluence east of Japan (including the ephemeral, mobile warm-core and cold-core rings; Nagata et al. 1986); at scattered locations in the Japan Sea; and probably in and around the Subtropical Front (i.e., around lat. 30°-32°N).

Perhaps the most impressive microscale convergences are in and around the Subarctic Front. Here, dynamic instabilities in surface layers (Roden 1970) create numerous ephemeral convergences in the zone lat. 37°-42°N and in the Oyashio-Kuroshio Confluence east of Japan. This juxtaposition of high biological productivity, physical complexity, large numbers of seabirds that ingest neuston plastic, and large amounts of neuston plastic increases the possibility of ingestion of that plastic.

ACKNOWLEDGMENTS

Most of the work was done while Day was an Angus Gavin Memorial Fellow, a Sea Grant Fellow, or a Resources Fellow at the University of Alaska. Additional funding came from the National Marine Fisheries Service (NMFS), NOAA (contracts 40ABNF63228 and 43ABNF702983) and two contracts from the Joint Institute for Marine and Atmospheric Research at the University of Hawaii. Additional samples were collected by James Seger and Richard Rowlett of NMFS and by Amy Stone of the U.S. Fish and Wildlife Service (FWS). Samples were collected aboard the TV *Oshoro Maru* of Hokkaido University, Hakodate, Japan; RV *Pusan 851* of the National Fisheries Research and Development Agency, Government of the Republic of Korea, Pusan, Korea; RV *Miller Freeman* of the Northwest and Alaska Fisheries Center, NMFS, Seattle, Washington, RV *Eagle* of the FWS, Homer, Alaska; and RV *Alpha Helix* of the Institute of Marine Sciences, University of Alaska, Fairbanks, Alaska. We thank the captains, officers, and crews of these ships for assistance in collecting the samples. This manuscript was improved by comments from three anonymous reviewers. This is Contribution No. 827 of the Institute of Marine Sciences, University of Alaska, Fairbanks, AK 99775.

REFERENCES

Balazs, G. H.
1985. Impact of ocean debris on marine turtles: Entanglement and ingestion. *In* R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii, p. 387-429. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54.

Bourne, W. R. P., and G. C. Clark.
1984. The occurrence of birds and garbage at the Humboldt Front off Valparaiso, Chile. Mar. Pollut. Bull. 15:343-344.

Carpenter, E. J.
1976. Plastics, pelagic tar, and other litter. *In* E. D. Goldberg (editor), Strategies for marine pollution monitoring, p. 77-89. Wiley, N.Y.

Carr, A.
1987. Impact of nondegradable marine debris on the ecology and survival outlook of sea turtles. Mar. Pollut. Bull. 18:352-356.

Cheng, L., M. Schultz-Baldes, and C. S. Harrison.
1984. Cadmium in ocean-skaters, *Halobates sericeus* (Insecta), and in their seabird predators. Mar. Biol. (Berl.) 79:321-324.

Conover, W. J.
1980. Practical nonparametric statistics, 2d ed. Wiley, N.Y., 493 p.

Day, R. H.
1980. The occurrence and characteristics of plastic pollution in Alaska's marine birds. M.S. Thesis, Univ. Alaska, Fairbanks, 111 p.

Day, R. H., and D. G. Shaw.
1987. Patterns in the abundance of pelagic plastic and tar in the North Pacific Ocean, 1976-85. Mar. Pollut. Bull. 18:311-316.

Day, R. H., D. G. Shaw, and S. E. Ignell.
1990. Quantitative distribution and characteristics of marine debris in the North Pacific Ocean, 1984-88. *In* R. S. Shomura and M. L. Godfrey (editors), Proceedings of the Second International Conference on Marine Debris, 2-7 April 1989, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-154. [See this document.]

Day, R. H., D. H. S. Wehle, and F. C. Coleman.
1985. Ingestion of plastic pollutants by marine birds. *In* R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii, p. 344-386. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. [See this document.]

Favorite, F., A. J. Dodimead, and K. Nasu.
1976. Oceanography of the subarctic Pacific region, 1960-71. Int. North Pac. Fish. Comm. Bull. 33:1-187.

Gregory, M. R.
1978. Accumulation and distribution of virgin plastic granules on New Zealand beaches. N.Z. J. Mar. Freshwater Res. 12:399-414.

1983. Virgin plastic granules on some beaches of eastern Canada and Bermuda. Mar. Environ. Res. 10:73-92.

Harrison, C. S., T. S. Hida, and M. P. Seki.
1983. Hawaiian seabird feeding ecology. Wildl. Monogr. 85:1-71.

Kawai, H.
1972. Hydrography of the Kuroshio Extension. *In* H. Stommel and K. Yoshida (editors), Kuroshio: Physical aspects of the Japan Current, p. 235-352. Univ. Wash. Press, Seattle, WA.

Masuzawa, J.
1972. Water characteristics of the North Pacific central region. *In* H. Stommel and K. Yoshida (editors), Kuroshio: Physical aspects of the Japan Current, p. 95-127. Univ. Wash. Press, Seattle, WA.

Nagata, Y., J. Yoshida, and H.-R. Shin.
1986. Detailed structure of the Kuroshio Front and the origin of the water in warm-core rings. Deep-Sea Res. 33:1509-1526.

Owen, R. W.
1981. Fronts and eddies in the sea: Mechanisms, interactions, and biological effects. *In* A. R. Longhurst (editor), Analysis of marine ecosystems, p. 197-233. Acad. Press, N.Y.

Roden, G. I.
1970. Aspects of the mid-Pacific Transition Zone. J. Geophys. Res. 75:1097-1109.

Sameoto, D. D., and L. O. Jaroszynski.
1969. Otter surface sampler: A new neuston net. J. Fish. Res. Board Can. 25:2240-2244.

Shaw, D. G.
1977. Pelagic tar and plastic in the Gulf of Alaska and Bering Sea. Sci. Total Environ. 8:13-20.

Shaw, D. G., and G. A. Mapes.
1979. Surface circulation and the distribution of pelagic tar and plastic. Mar. Pollut. Bull. 10:160-162.

Shomura, R. S., and H. O. Yoshida (editors).
1985. Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54, 580 p.

Wolfe, D. A. (editor).
1987. Plastics in the sea. Mar. Pollut. Bull. 18:303-365.

Wong, C. S., D. R. Green, and W. J. Cretney.
1974. Quantitative tar and plastic waste distributions in the Pacific Ocean. Nature (Lond.) 247(5435):30-32.

Zar, J. H.
1984. Biostatistical analysis, 2d ed. Prentice-Hall Inc., Englewood Cliffs, NJ, 718 p.